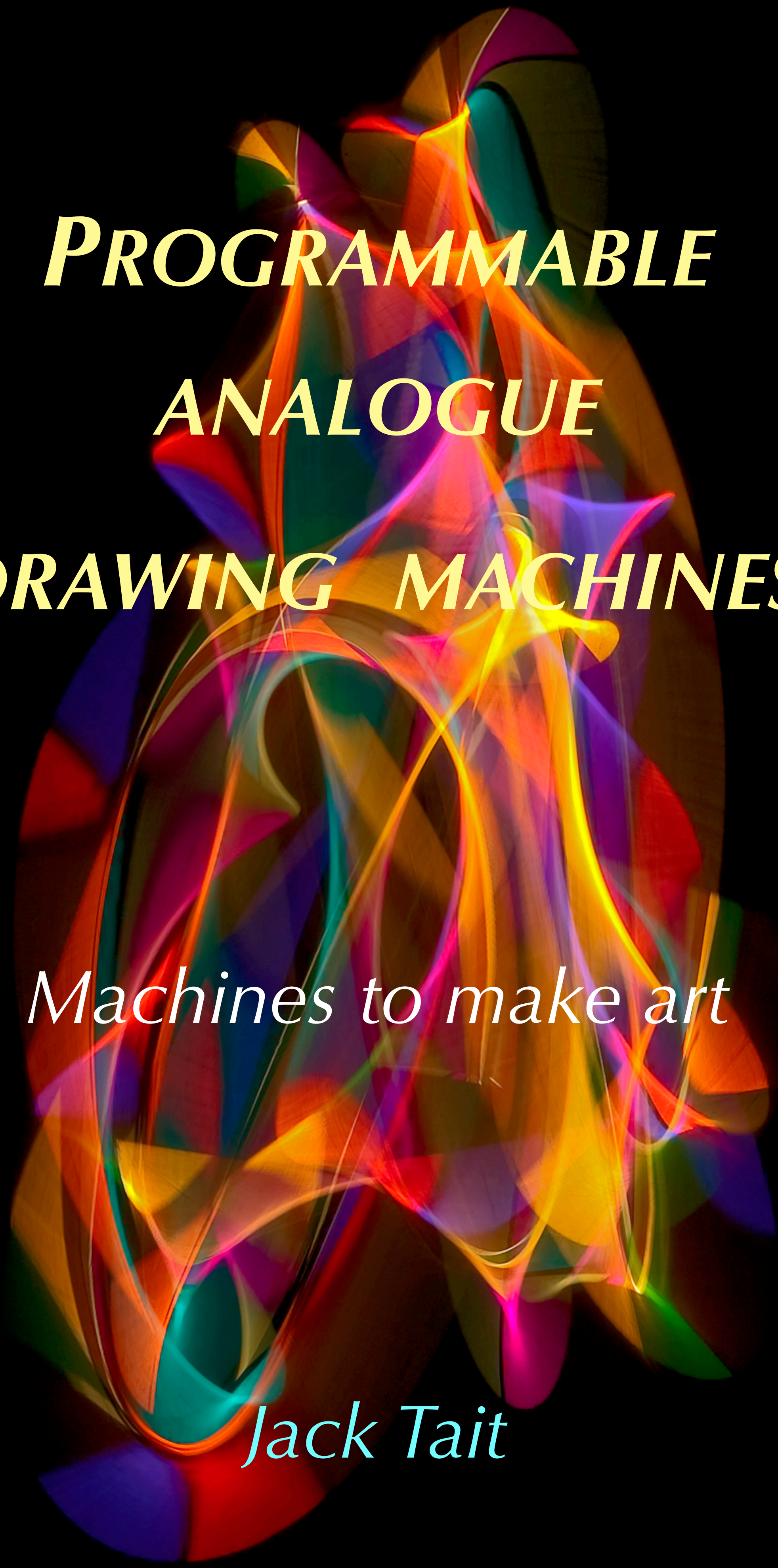


PROGRAMMABLE ANALOGUE DRAWING MACHINES

Machines to make art

Jack Tait

CONTENTS

Dedications and acknowledgements

This book is dedicated to John Sharp without whose help and encouragement it would not have existed. Thanks are also due to Paul Brown, Phil Husbands, Penelope & Adam Woolfitt, the Computer Arts Society and my wife Rita.

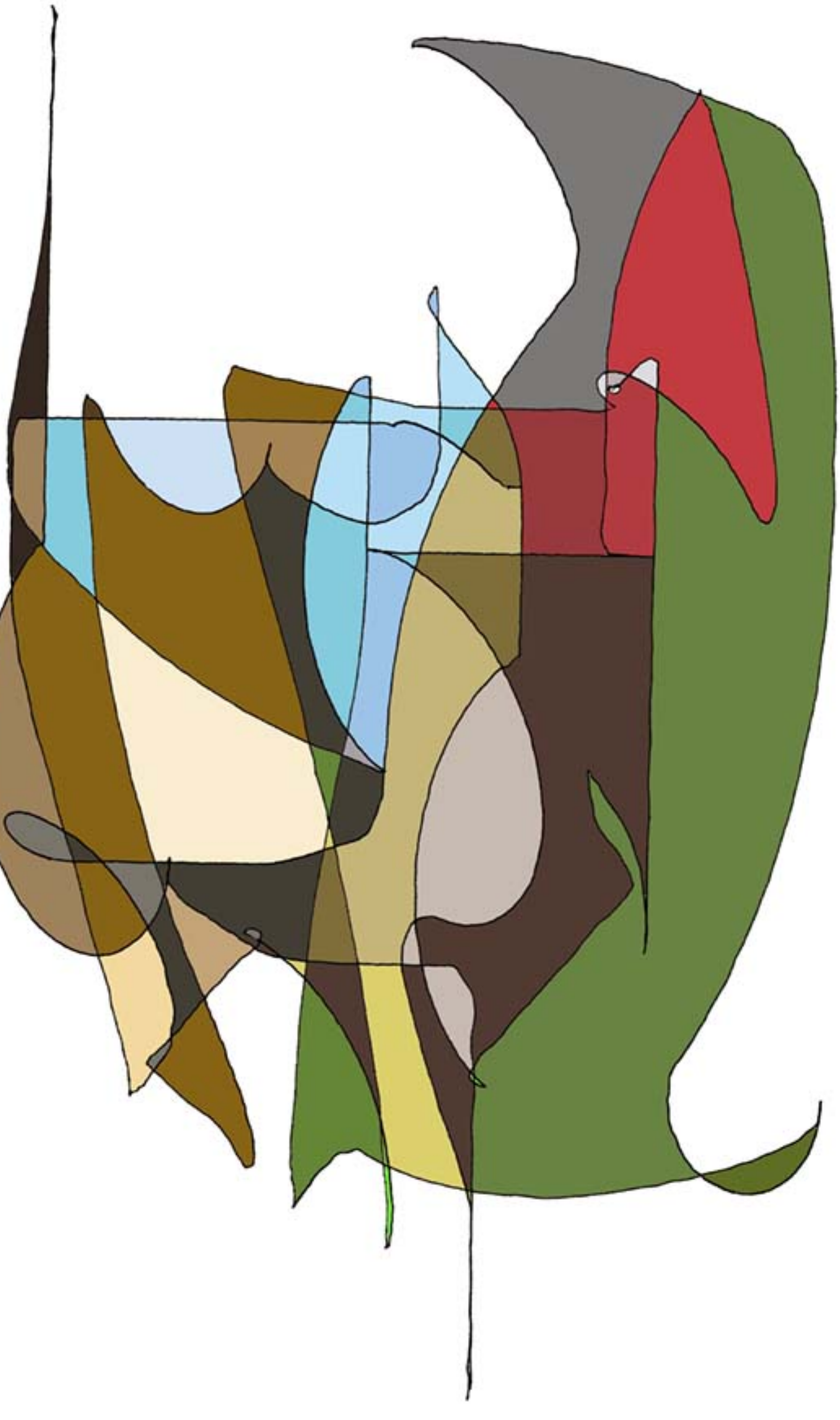


fig 1 *This image and the front cover is what the book is about.*
The art works come first, the machines second.

INTRODUCTION

This book is about drawings made by simple electro-mechanical machines, using line, colour and light and explores their ability to make art works. The machines are programmable, obeying simple instructions, combining deterministic controls and quasi-randomness. The motivation is curiosity; how simple numeric instructions can produce complexity, consistent with the emergence of chaos theory in the 20th c.

Analogue machines and art have been associated for a very long time. In the 1st c AD Heron of Alexandria made many machines such as a wind powered organ. (Sharkey,2007) In AD 1206 al Jazari made machines like his elephant clock (Nadarajan,2007) which was a programmable automator conceived as an art work. Within such a broad group of machines, spread over a long time scale, a narrow subset of machines may be proposed culminating in those designed to make static two dimensional art objects. Most analogue drawing machines in the past, being utilitarian, fall outside this set. Fewer still were designed and made by the artist to make art works and subjected to control by a programmable timer. Past machines were often scientific tools or drawing aids (Rigge,1926) whilst most current ones are now digitally controlled. Contemporary analogue drawing machines, often ending up more as sculptural works, produce random results without timer control or repeatability, (Hoehn,2008). In Balint Bolygo's case the results are exceptionally intriguing, (Bolygo,2011). An exception where programming was used is the work of John Whitney, (Moritz,1997). Paul Desmond Henry, (O'Hanrahan,2005), produced beautiful drawings from a WW2 analogue computer and whilst it had some programming capacity Henry chose to emphasise the random aspects and regarded each as unrepeatable. This historical context places my machines in a small subset. Their unusual nature resulted in a PhD at Manchester MMU MIRIAD in May 2011.

The machines were made with the specific intention of making art works; the text and illustrations are intended to show how simple instructions generate complex images. In sections below, concepts, method and evaluation are addressed. Contents cover intent, design, production, programming, pseudo-randomness, light-drawing, colour, Photoshop post-production and repeatability. The latter point is particularly important if a machine is to be used as a design tool rather than being just a 'press a button and see what happens' device.

Delegating control to a machine raising fascinating questions about art process, whilst engineering problem-solving gives insights into design process. The philosophical points arise from conceptual, mechanical and evaluation aspects involving questions of meaning, value judgements, and aesthetic qualities of line and colour. All these might combine to offer some insights into art process.

Whilst this book is derived from my PhD thesis I have emphasised the practical aspects of drawings, machines, and timers. Detail necessary for a formal academic thesis, has been omitted. Emphasis on practical and pictorial aspects might encourage artists/designers to built their own machines exploring machine drawing on their own terms.

2. OVERVIEW ***Machines, timers and drawings***

Usually people are keen to see the machines first and then look at the drawings so I have begun by showing all the machines made over a period of 50 years. I describe some, then look at the timers and light units which work with them. Following this I review some of the drawings, mainly chosen from the exhibition which accompanied my PhD submission.*

My interest in drawing machines began early on, designing them from Meccano. During my Royal Air Force service, work in photo-reconnaissance research brought me into contact with machines which converted radar images into colour contour maps. This started me thinking about drawing with light. My career in art education went alongside machine making which continues up to the present.

Eventually these machines, timers and some drawings might be displayed at the Science Museum who have acquired them for their collection. Given the volume of work undertaken it might be some time before they are on display.

In the text I will be using some words specific to engineering, physics and maths. These are covered in the Glossary of Terms following the Bibliography. If you are from a general or art background it might help to look at the terms first.

After the overview I reflect on the whole process looking in turn at context, concept, method and evaluation. There is a fundamental difference between using a machine to make art and conventional drawing and painting. Appreciating this from the outset could be helpful in making sense both of the process, evaluation and the philosophical questions which arise.

NOTE:-   COMPUTER WORK - see last 10 drawings on the last images page

In the early 80's I acquired a vintage 1969 Hewlett Packhard computer calculator and plotter as part of a study I was involved in. With this I was able to try out some drawing ideas covering the areas I later developed in my analogue machines namely sinewaves, circular images and constructivist programs using grids and random selections. The machine was incredibly slow with limited capacity and eventually stopped working. Given this I returned to building analogue machines as in 1982 the computer facilities available were either formidably expensive or limited in their facilities. Ten examples are shown above and were included in my PhD exhibition. The colour was added to these drawings much later on in Photoshop.

* *Footnote*

The degree was a new type which revolved around professional practice. The submission rested on an exhibit, a viva and a smallish thesis of around 45,000 words. The full thesis may be accessed at Manchester MIRIAD MMU. It is one of the foremost establishments in the UK for post graduate work in art and design.

The overview can begin by looking at one or two early drawings to establish a start point and then go on to see the timeline of machines as they were built and modified.

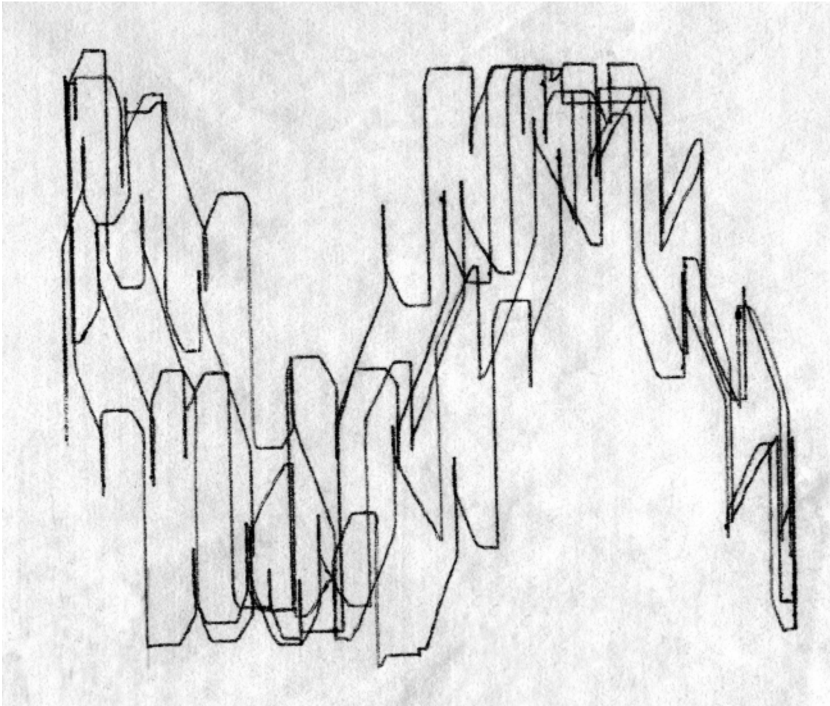


*fig 2 Early drawing from machine in '**1**' pg 10 c 1972*

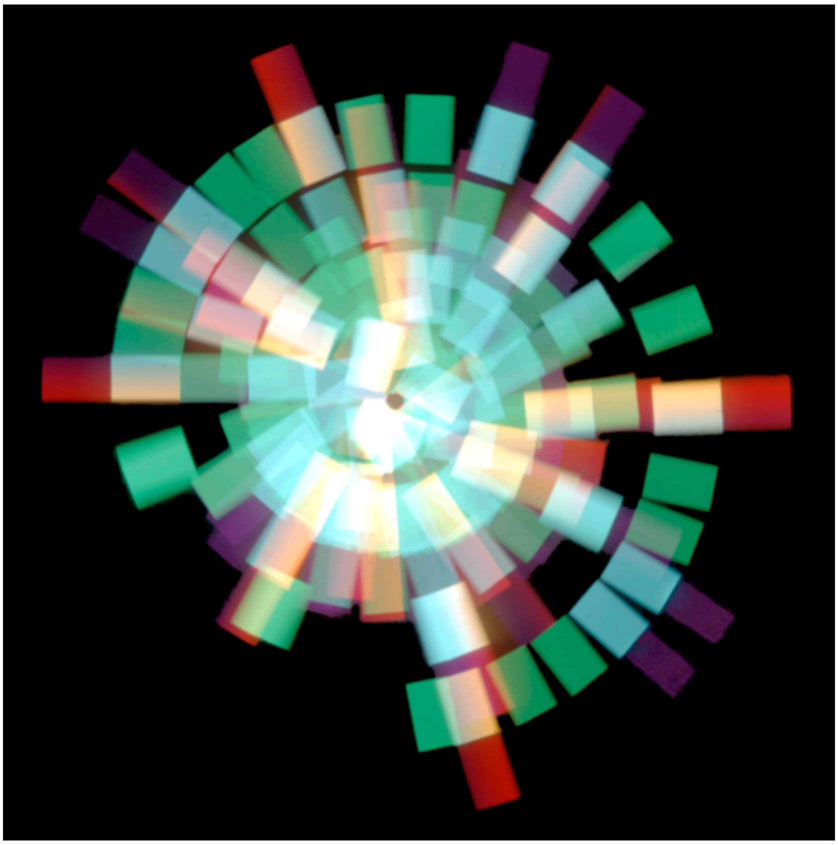


*fig 3 Colour light image '**3**' machine pg 10*

The first panel of machine illustrations below shows early machines, a set of those which are not based on Lyssajous figures or are designed as X:Y plotters. **'1** to **3'** are rather crude early machines. **'1'** was a simple plotter type partly made from Meccano which had X,Y directions coupled with double auto-reverse gearboxes. This was to increase the richness of the drawing. It worked but made small drawings with relatively poor line quality. See pg 6.

'3' was a very simple box on wheels which ran along an enlarger baseboard and exposed film from the enlarger image above. A rotary shutter and colour wheel below the enlarger lens 'chopped' the images into segments. The machine in 2. is my first programmable machine with an inbuilt timer and drum for the platen.
It produced a variety of good images, which were used in the PhD exhibit.

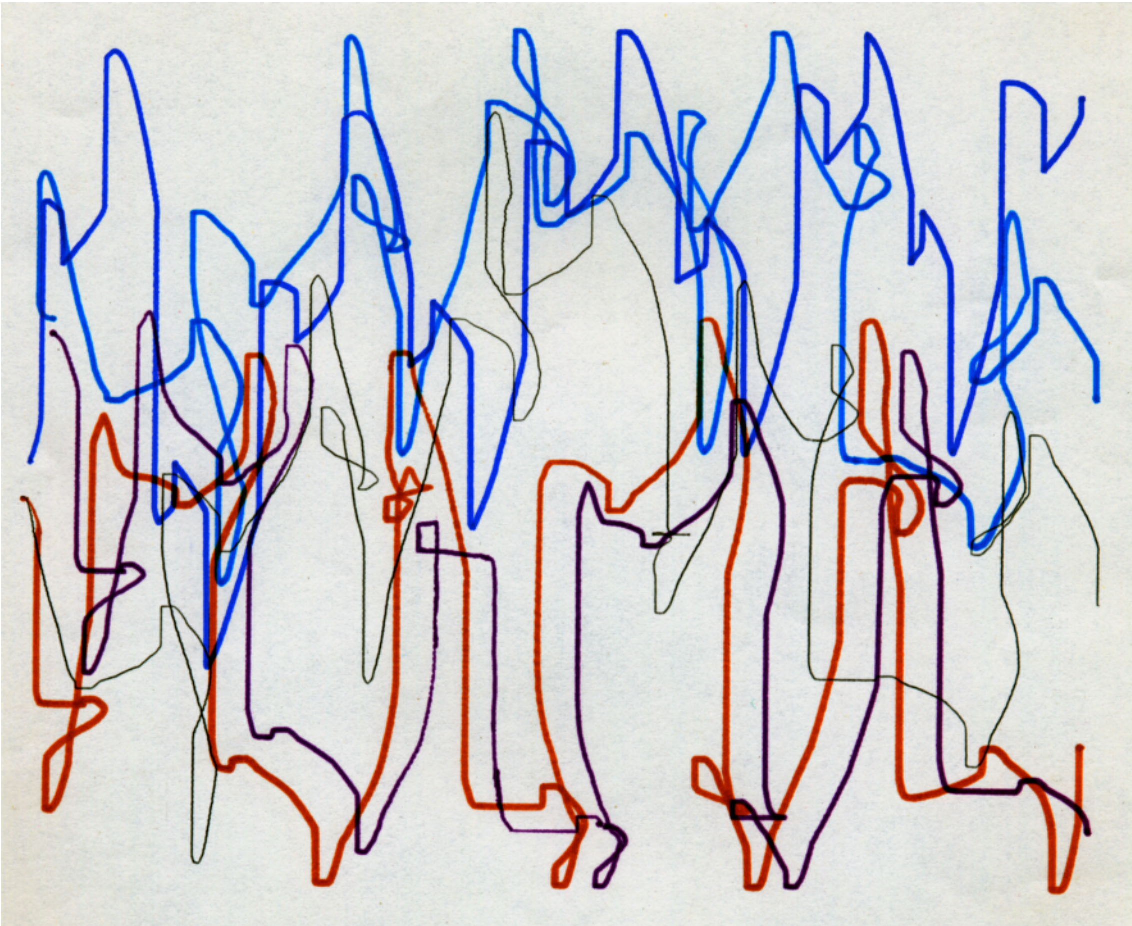


*fig 4 Early drawing from the drum machine in **2***

Machines '**4,5** and **6'** were different versions of the Sinewave machine whilst '**8'**is the Scibblogram able to draw a form of cross hatching at different locations. **'7'** is a device for analysing the timer outputs in graphic form. The rest **'9 -12'** are different versions of the Turntable machine, the last one dates from 2010. Images from all these machines except **'7'** are shown in the drawing sets so do not need to be shown separately.

The second set of machines all generate Lyssajous figures from the simple Meccanographs **'5-8'** to the Linkograms in **'1-4'.** The Linkogram mimics the action of a pendulum Harmonograph with added turntable and pen lift mechanism. Unlike a harmonograph it can be programmed to repeat a drawing with some accuracy.

Many 'Marks' of many machines were made in pursuit of line quality, avoiding wobbles due to backlash in the bearings. A high quality was finally achieved where the aim was to have the line space equal to1.5 times the line width.

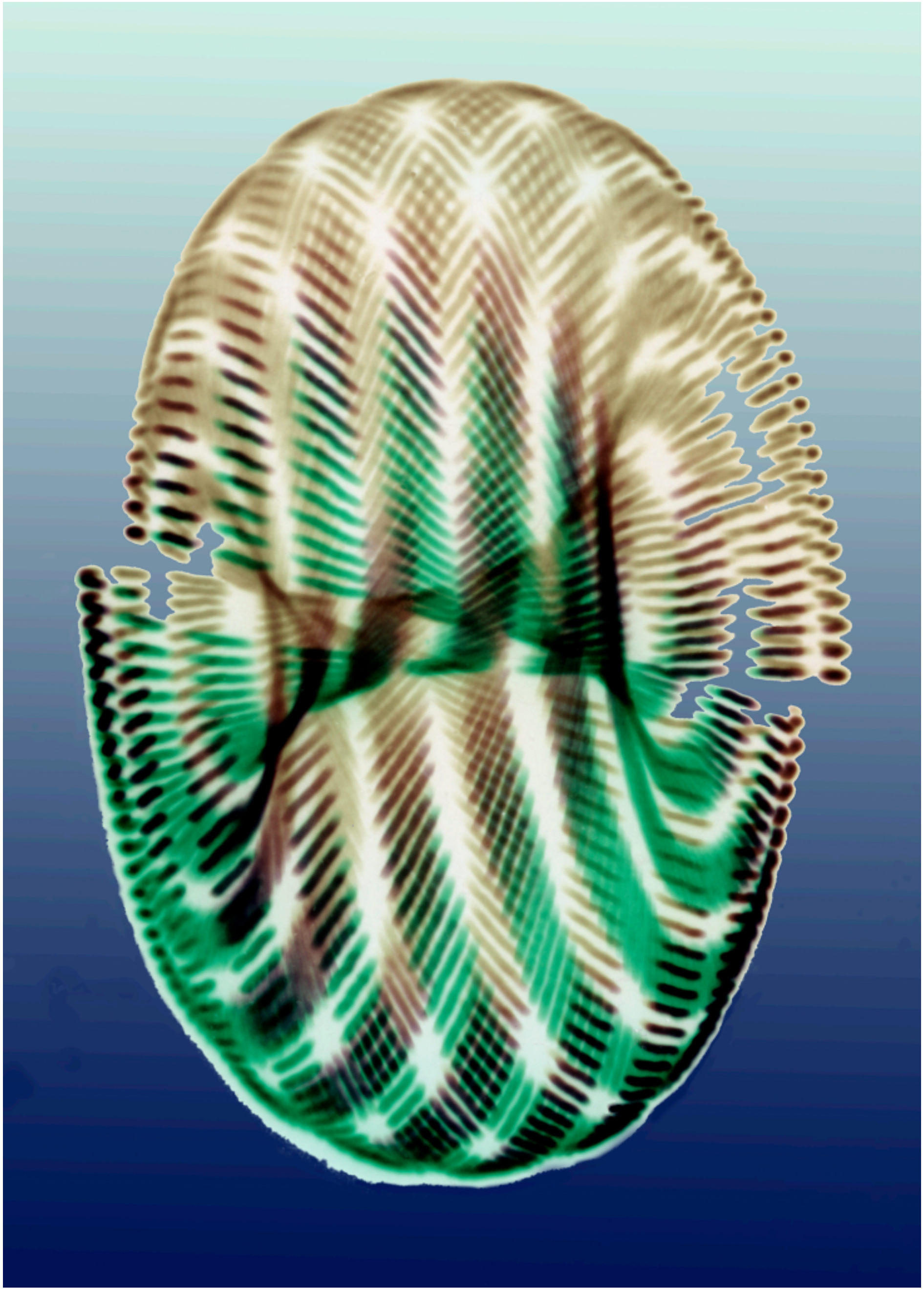
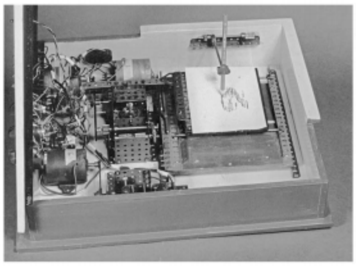


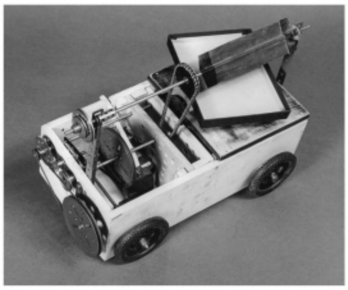
fig 5 An early colour light drawing on film from a forerunner of the Linkogram machine

EARLY, SINWAVE, PRINTER, SCRIBBLOGRAM & TURNTABLE TIMELINE

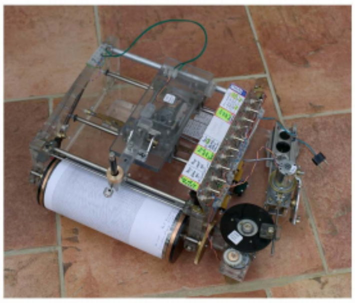


1. *Early NSEW machine ~1971*

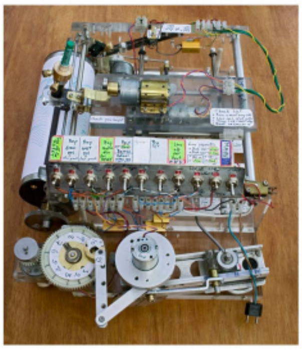
2. *Early drum machine & timer~1972*



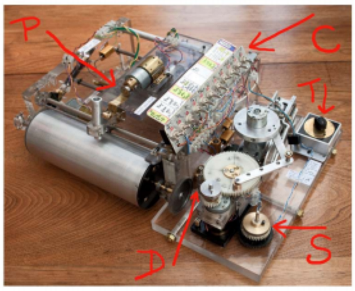
3. *Early light Turntable ~1973*



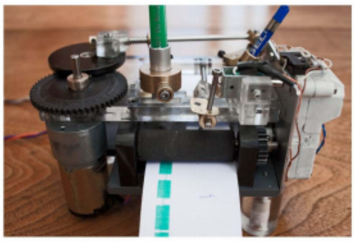
4. *Sinewave MkI 2005*



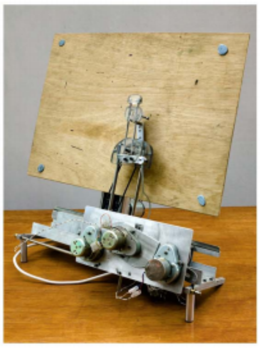
5. *Sinewave MkII 2007*



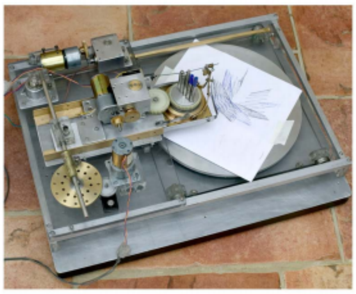
6. *Sinewave Mk III 2009*



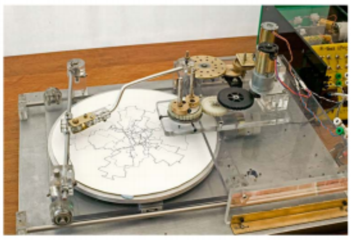
7. *Time printer MkII 2009*



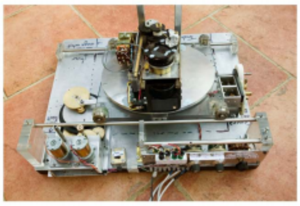
8. *Scribblogram 2008*



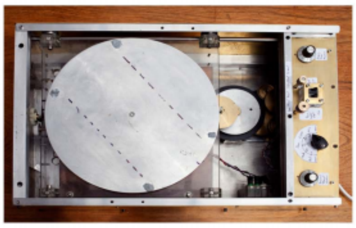
9. *Turntable MkI ~1999*



10. *Turntable MkII 2007*



11. *Turntable MkIII 2007*



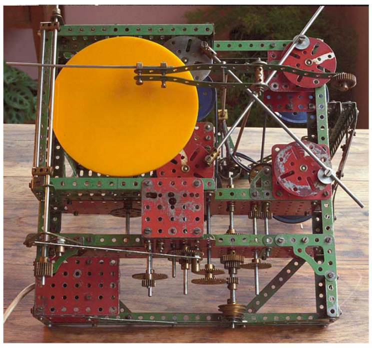
12. *Turntable Mk IV*

2010

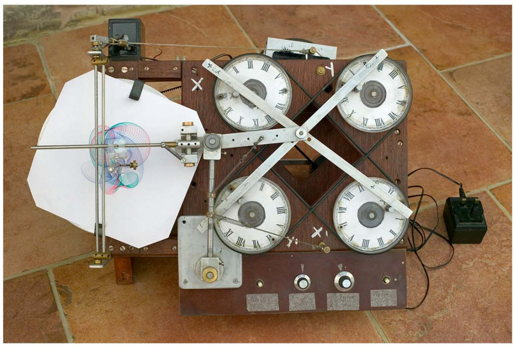
fig 6

*This set is a mixed group. '**1** and **8**' are X:Y plotter based, '**2,4 5** and **6**' use a drum as a platen, '**7**' is a time measuring device with a graphic output whilst '**10,11**' and '**12**' are turntable based. '**3**' does not fit any category and is as simple a light machine as it is possible to make.*

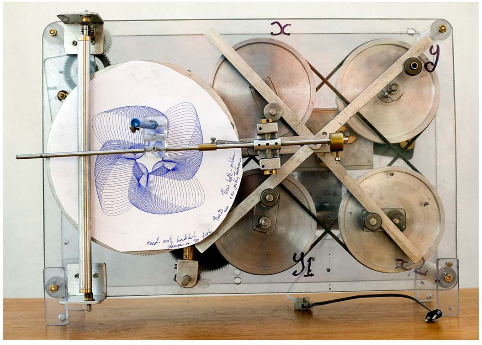
LINKOGRAM AND MECCANOGRAPH TIMELINE



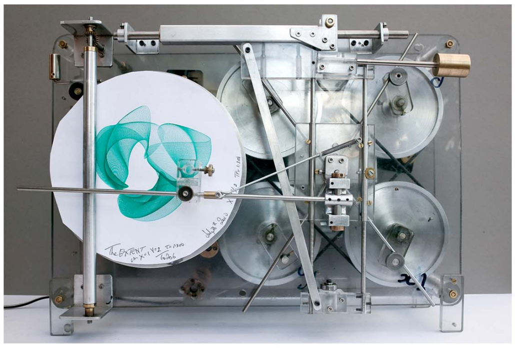
***1.** Meccano Linkogram 1997*



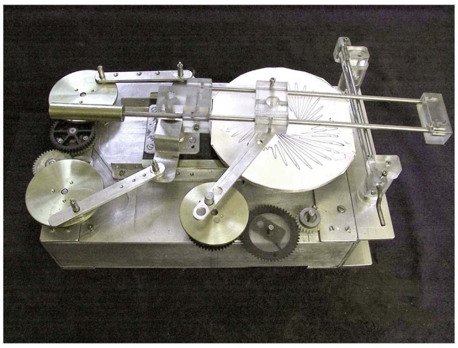
***2.** Linkogram Mk I 1999*



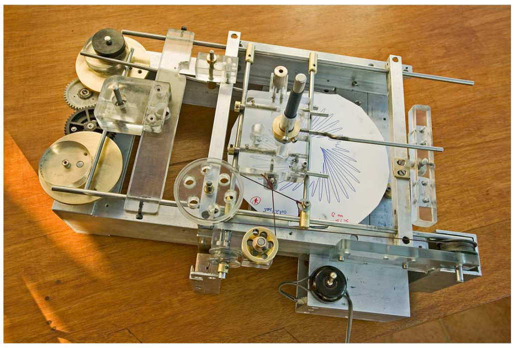
3. Linkogram Mk II 2007



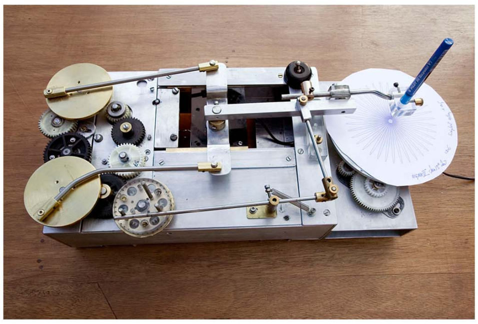
***4.** Linkogram Mk III 2010*



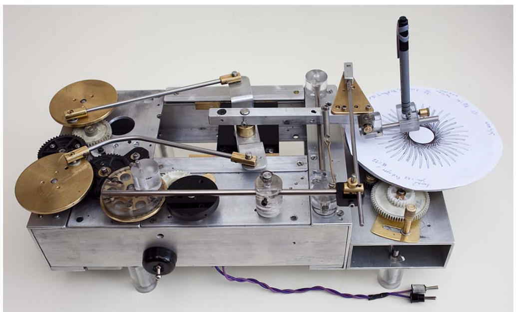
***5.** Meccanograph Mk I 2007*



***6.** Meccanograph Mk II 2007*



***7.** Meccanograph Mk III 2009*



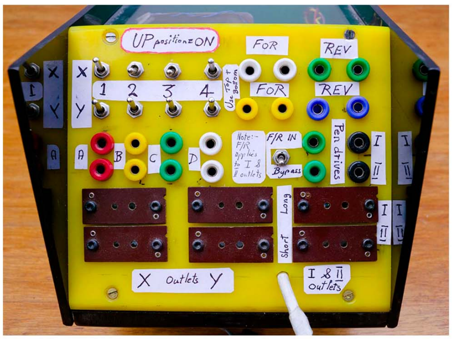
***8.** Meccanograph Mk IV 2010*

fig 7

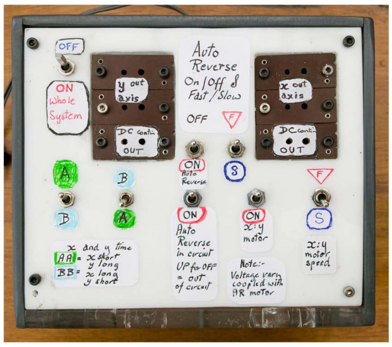
Some machines, Meccanograph, Linkogram, Sinewave and Turntable can make drawings relying on internal settings for their programming. Those based on X:Y plotter design depend on control by a timer which switches on the motors in sequence. Timers have played a crucial part in the exploration of 'simple instructions leading to complexity'.

fig 8

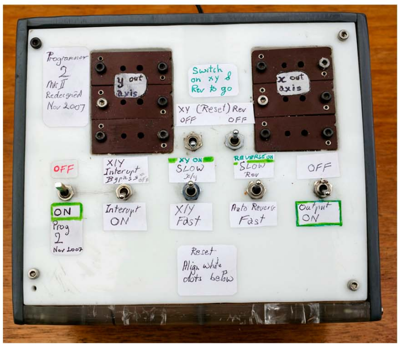
TIMERS TIMELINE



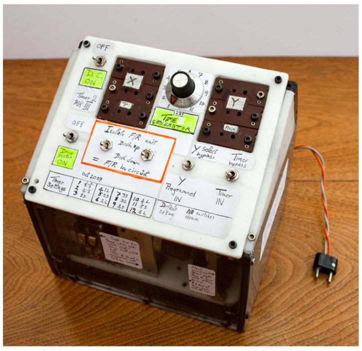
1. *Timer 1 MkII 2007*



2. *Timer 2 Mk I 2005*

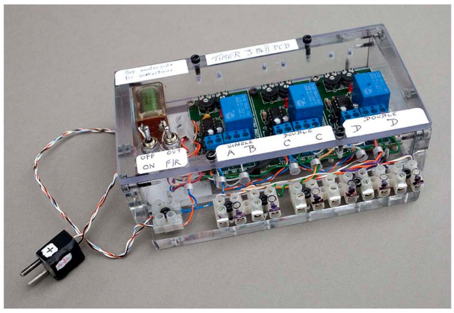


3. *Timer 2 MkII 2005*

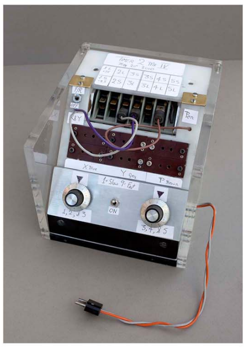


4. *Timer 2 MkIII 2009*

5. *Timer 3 Mk I 2008*



6. *Timer 3 Mk II 2010*



7. *Timer 2 MkIV 2010*

8. *Timer 4 Mk II 2010*

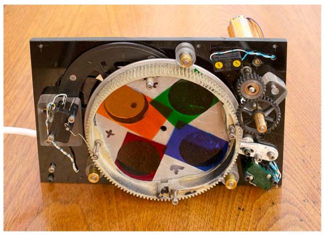
Timer 1 in '1' was an effective first attempt in 2007 and subsequent designs of Timer 2, in '2,3,4' failed to match or complement the versatility of Timer 1 until MkIV in '7'. Its success attributable to twin sets of varying speed cams and multiple outlets from the wander leads. Timer 3 was disappointing, whilst Timer 4 had a near 'digital' feature with its alterable pin programming. It was however very complex mechanically so Timer 1 was probably the best all round model.

fig 9

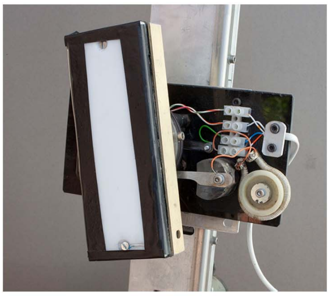
LIGHT UNITS AND CAMERA RIG TIMELINE

1. *Large light projector ~ 2004*

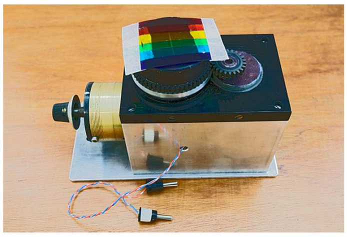
2. *Colour changer casing ~2008*



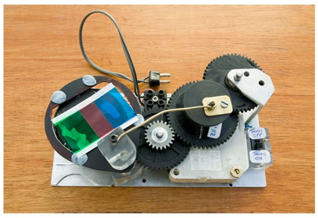
3. *Colour changer inards ~2008*



4. *Large slit light unit 2008*



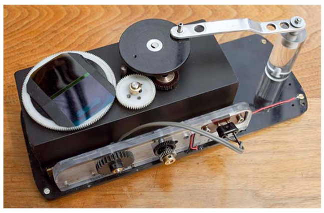
5. *Light unit Mk I 2005*



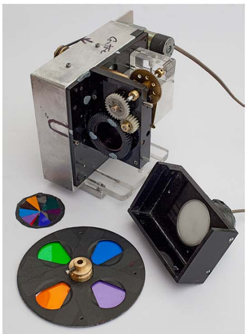
6. *Light unit M II 2006*

7. *Camera on cradle 2010*

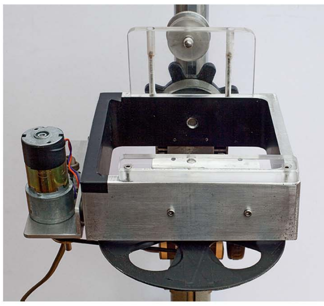
8. *Light unit Mk III & Mk IV 2009*



9. *Light unit Mk III & IV. on platform 2009*



10. *Light unit Mk IV 2010*



11. *Top camera frame 2010*

12. *Whole operating set up 2010*

Light pens have been used alongside graphics since the research began. A very crude version is in '3' above in Early Machines. The design of light pens has improved with a reduction in size, some 'streamlining' and the adoption of LED bulbs. The single most significant advance was the ability to employ a high end digital camera on the platens of the machines. With this advantage more light drawings were completed for the research than in the preceding 49 years.

Drawing sets as used in the exhibition

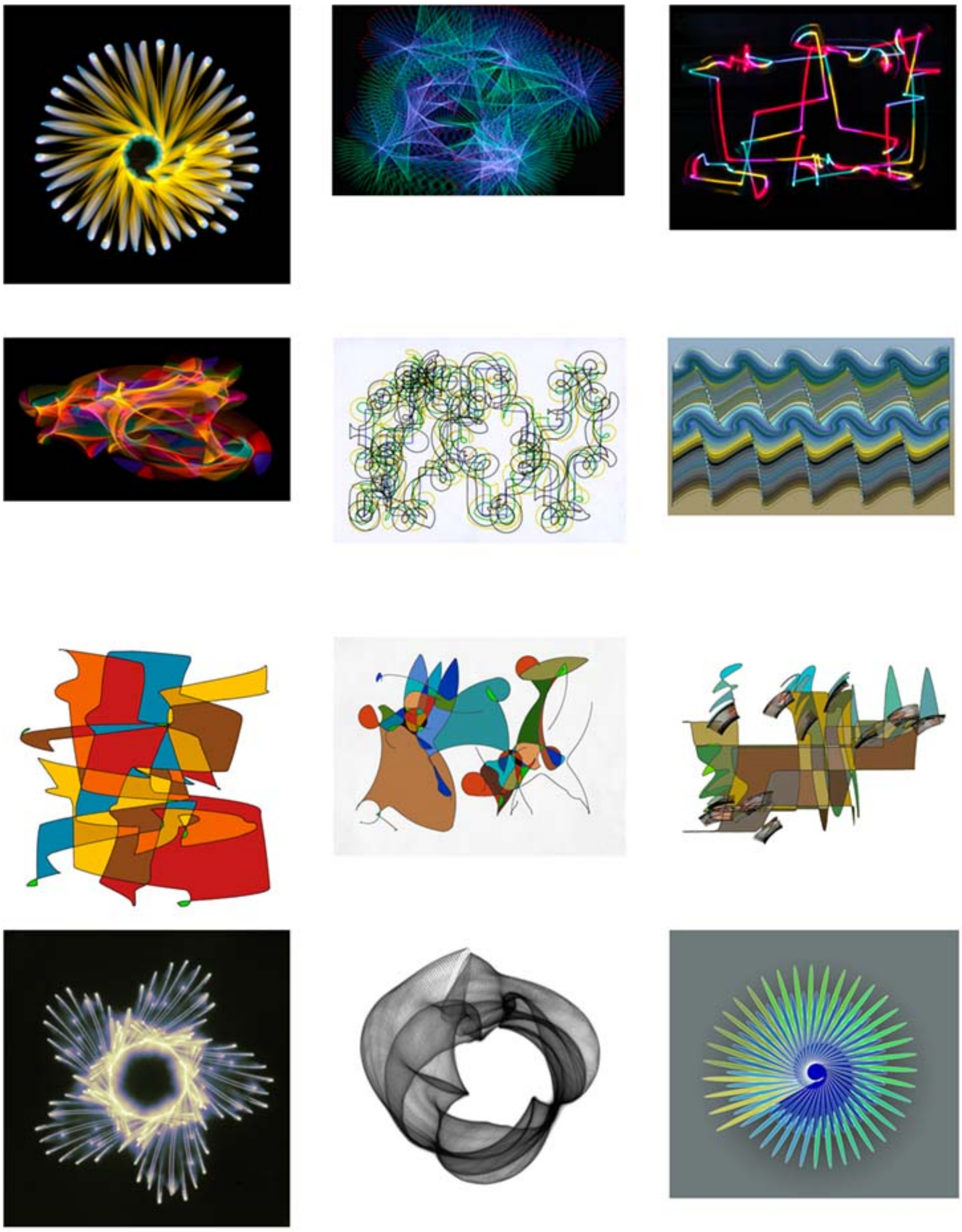
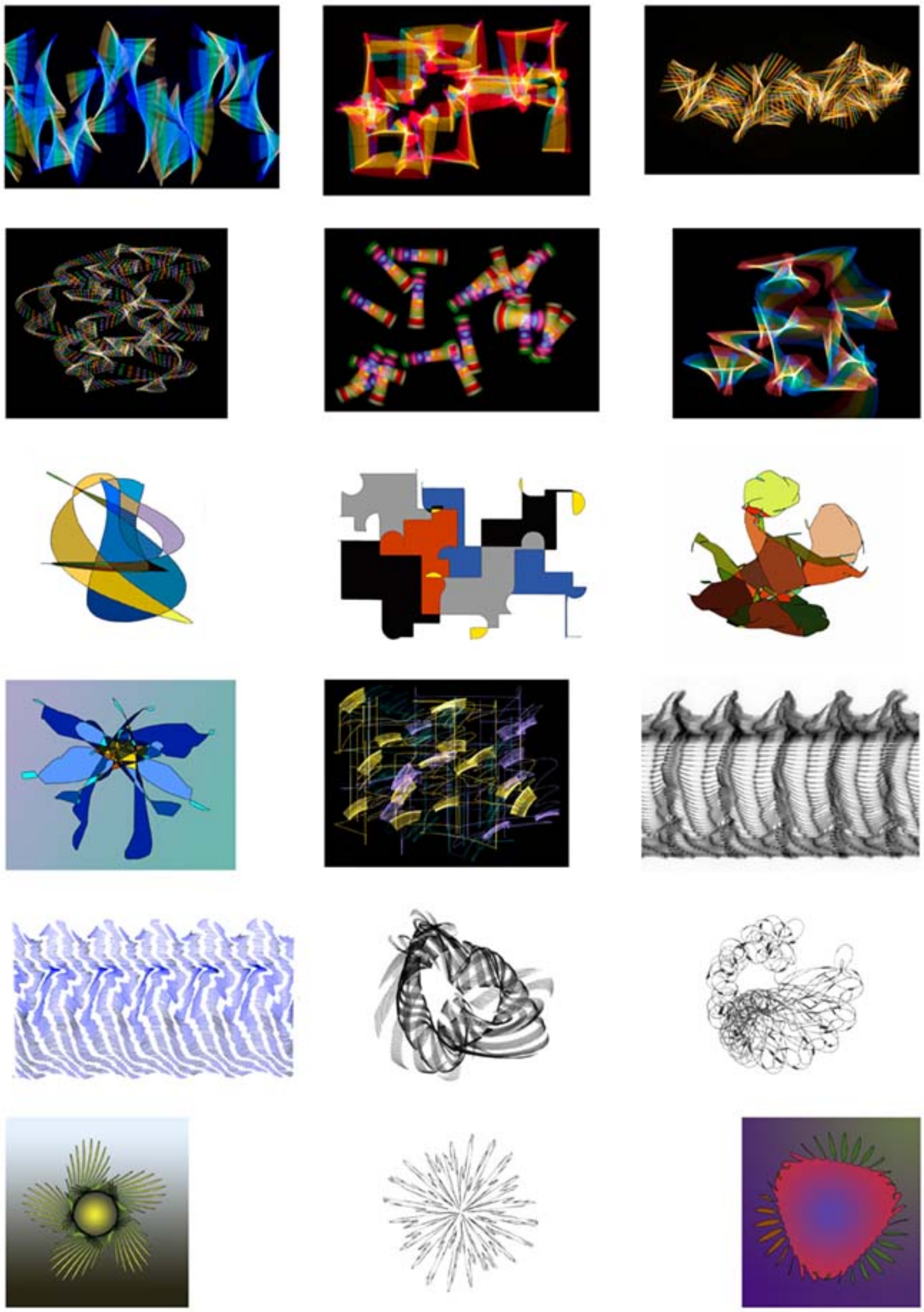


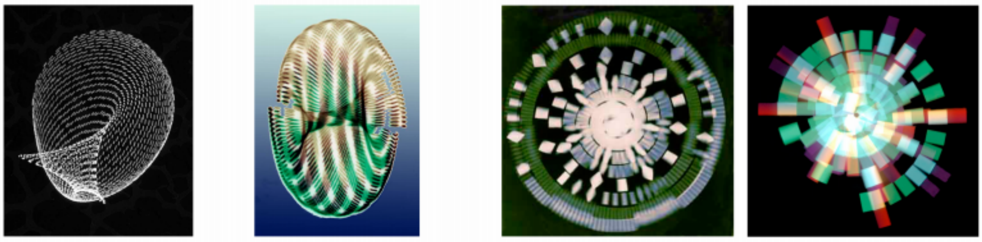
fig 10

These images and others below were chosen for my PhD exhibit and represent what I felt were the best results. Most graphic drawings go through a stage in Photoshop whilst the light images tend to need less after-work.

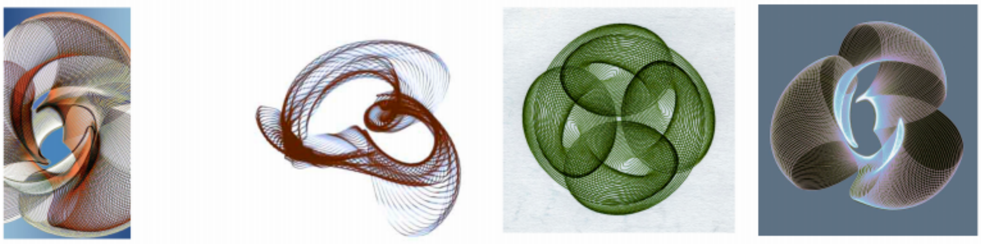
fig 11



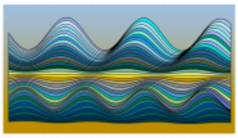
One problem in using machines to make art works is the very large number of potential images which could be produced. I have found that I rely on a straightforward intuitive approach and select a proportion of drawings to carry forward and make final choices from these.
fig 12



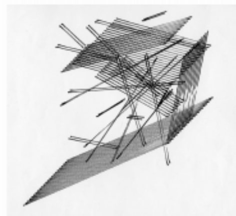
Four early light images

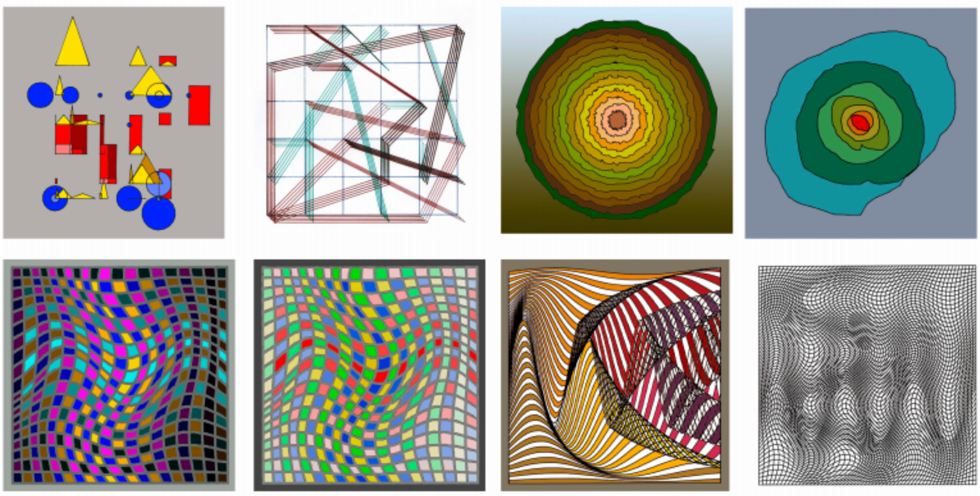


Six early graphic works
on early machines



Ten early examples of Hewlett
Packard Computer plotter work





This selection of images is to demonstrate the range and variety of drawings produced and the treatment applied to the original machine output. In later chapters I describe each machine, its drawings and process.

3. REFLECTIONS ON PROCESS - CONTEXT

It might be helpful now to reflect on the process of making art works with a machine and address the questions which have arisen during the years of activity.

Delegating some control to a machine to make artworks raises interesting questions about art process, although I accept that as designer and programmer I control the overall ideas. Aspects of hand and eye co-ordination are set aside in favour of the sometimes unpredictable outcomes of the machines. The first step might be to examine the context in which the machines are found.

Questions relevant to using machines were explored in the BBC 4 documentary (Secret Life of Chaos, 2010). Turing, Belousov and Mandlebrot explored the mathematics of chaos, phyllotaxis and morphogenesis. Without external intervention, they cited the tendency of systems to resolve chaos and generate ordered patterns. Turing (Turing, 1952) combined an interest in morphogenesis, where living things develop organised structures (e.g. Zebra stripes) and with Fibbonacci phyllotaxis[fig13] where the spirals in plant forms follow the Fibbonacci series. The Belousov-Zabotinsky reaction[fig14], (Peterson,1998) researched stability in solutions and Mandelbrot[fig15] (Mandelbrot,1982) researched self-similarity and fractals. However strict the deterministic control the outcome tended to be unpredictable, due to the problems of determining an exact starting point.

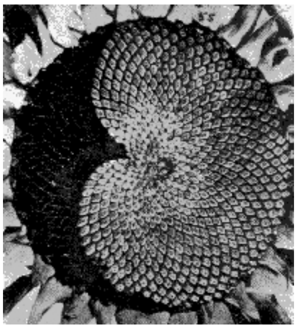
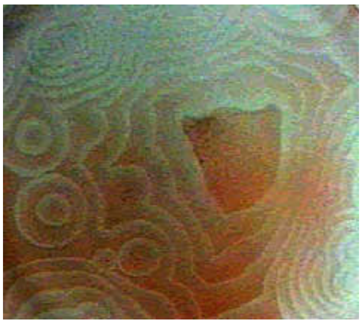
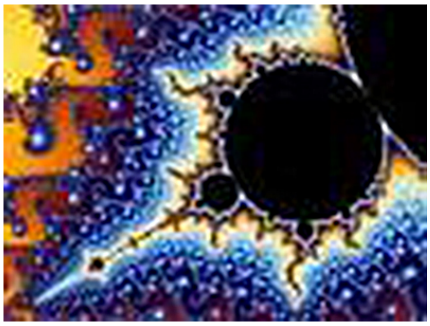
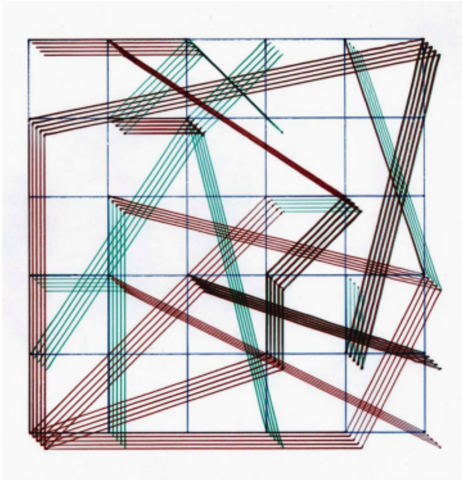




fig13 *Turing's 'Fibbonacci' phyllotaxis, fig14 Belousov's reaction, fig15 Mandlebrot's fractals*

In a lesser way this 'starting point problem' features in the sophisticated versions of my programmers, partially explaining difficulties experienced. It is encouraging to share preoccupations with movements of such significance in the later half of the 20th c. Work with programmable machines, a pseudo-random input has in some way mimicked a chaotic system.

I have been surprised at the tendency for a partially random system to generate aesthetically pleasing drawings more frequently than chance might suggest. The relationship between chance and order was the topic of Kenneth Martin's work in the middle of the 20th c. (Martin,1975) [fig17]. The work done with my machines carries on in this direction, exploring it in mechanical ways.



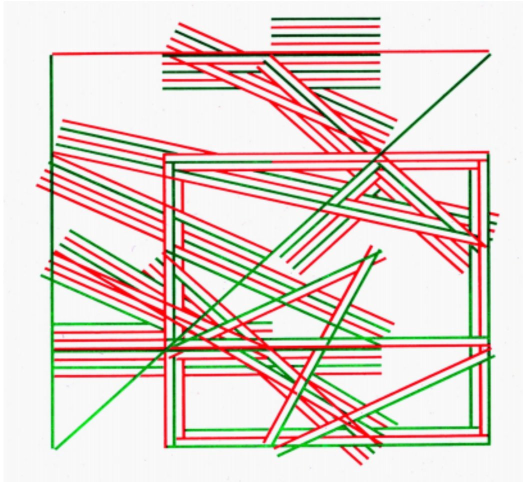


fig16 'Homage to Kenneth Martin', digital computer plot on Hewlett Packard computer
fig17 'Chance and order' 1971-72 (Martin,1975)

Research and literary searches have clarified basic ideas emphasizing intent, the ability of simple instructions to generate complex drawings and highlighted programming. These factors, albeit embedded in an analogue system rather than a digital one, moves the emphasis from simple mechanical systems to the richness and complexity of sequential instructions.

4. REFLECTIONS ON PROCESS - CONCEPT

Original intentions

Original intent or initial concept is one of the essential prerequisites in building drawing machines. Both Max Chandler (pg 9 & 10 above) and myself have found that this intent has been lacking in many practitioners whom we have come across. Each Taitograph machine is built to explore a particular facet of the research under the umbrella of 'Simple instructions can lead to complexity'. A secondary consideration is refinement of components, or additional devices, stemming from previous faults. In a complex machine, practical steps are essential. Painting can be different; it is feasible to start with a blank canvas, make a mark and then see where it takes one. Many decisions in machine making are addressed before construction. Drawing character may be visualised and lead to the design of mechanisms to produce it.

A plan exists in operational terms and is not difficult to cite it as a criterion. If a machine draws sine waves, with growth or decay and wave-break shapes, the success or failure is immediately apparent. Trial and error takes place until the drawings are useable. In non mechanical terms, a subjective element is inevitable. From the outset, running parallel with the practical planning, a notion of what the drawing will look like exists. This may seem vague in theory, but in practice works well and is a reliable guide to progress. See also **Evaluation**-criteria below.

Role of drawings

Considering the relationship of the drawing to machine, is the purpose to make finished art works or are the drawings secondary? Max Chandler (Chandler,2008) addresses this below. Tinguely (Tinguely,1982) built kinetic sculptures, some of which made drawn outputs, but the principal intent was not to produce graphic art works. The machines were the art works; his intent was to question the nature of the art object, and the existence of drawings helped but were secondary.

The implication calls for specific divisors. Max Chandler, an American artist who uses machines to make his art works, addressed this question in correspondence saying:-

"Sadly very few (builders) start from an aesthetic goal and then make their machine" he continues *"Your first way to start categorizing would be to divide on whether the art is a by-product of the invention or whether the machine was specifically made to generate a kind of art".* Chandler continues,*"Few of the machines I see have anything like an artistic intent and certainly are lacking your deep understanding of your goals and results".*

Notions of intent, clear goals, definition of machine versus tool, lead to considerations of programming with timers, pseudo-randomness, and repeatability are all touched on below in **Method.**

Curiosity, motivation and fulfilment

Taitograph machines explore the ability of simple instructions to generate complexity, as do fractals. The motivation is curiosity; the satisfaction of seeing drawings emerge with characteristics, unimagined before the event, constitutes fulfilment. Later in the research, the drawings exhibited gesture-like qualities of line analogous with hand drawing. See also **Evaluation** below.

With added colour, similarities to hard edge abstract paintings emerged such as some by Cohen (Cohen,1983). Questions about art process may became pertinent if images can be mistaken for those made by hand. This adds intellectual stimulus, sitting alongside design problem-solving in the engineering and sculptural aspects of building.

Whilst such questions are intriguing they are subservient to exploring the outcomes of analogue machines. At this juncture it might help to look at some drawings which display concepts carried out. Meccanographs illustrate simple ideas which lend themselves to development and embellishment.

Four Meccanograph drawings

Four simple original concepts with enhancement post scanning in Photoshop

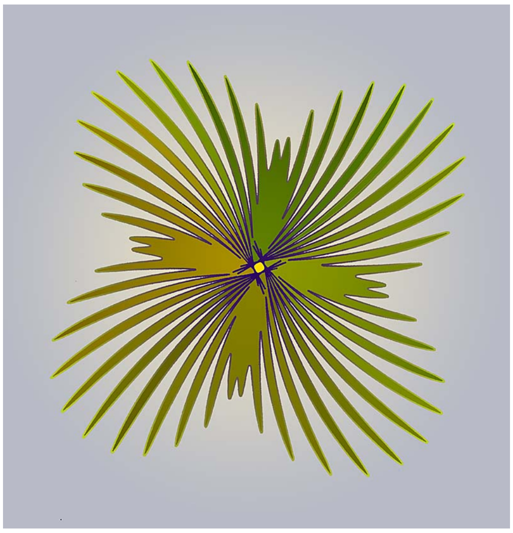


fig28

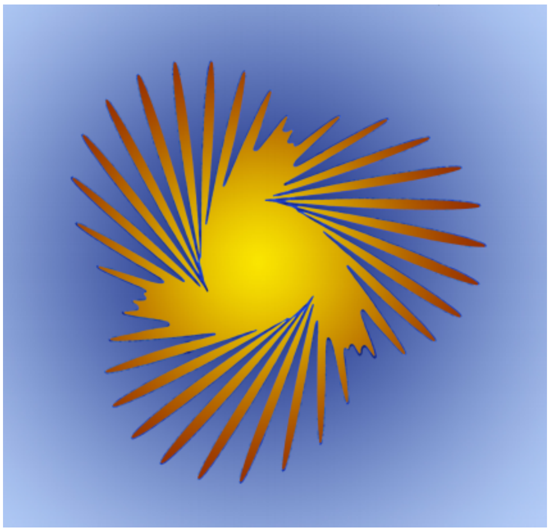


fig29

fig30

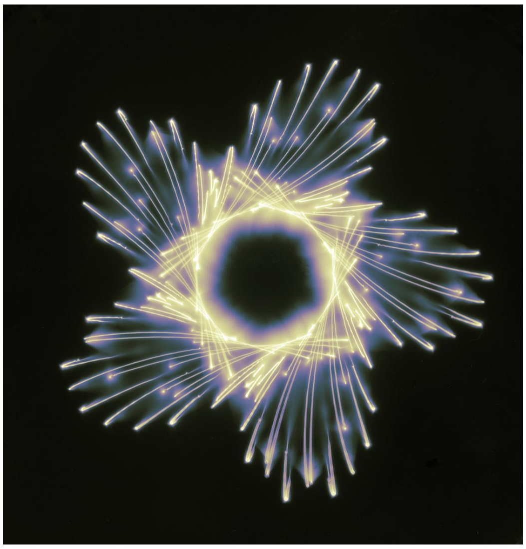


fig31

The restricted range of the Meccanograph still allows individual Photoshop interpretations. Figs28 & 29 are graphic drawings converted in Photoshop, fig30 is a five colour pen drawing and the fig31 is an inverted light pen drawing onto photographic paper. To fully influence style, decisions usually need to be made before the post production stage.

Whilst the Meccanograph and Linkogram are machines rely on variations on Lyssajous figures and have a mathematical basis there is another set of machines controlled by programmed input of X and Y coordinates which are made as X:Y plotters. Two are called North, South, East, West machines, NSEW for short. A third machine was based on a turntable with an added X input. With these it is possible to extend the range and variety of concepts to be explored.

NSEW and Turntable drawings

More complex concepts are involved when programmers are used in the NSEW and Turntable machines. I have selected a number of examples of varied images to explore this notion.

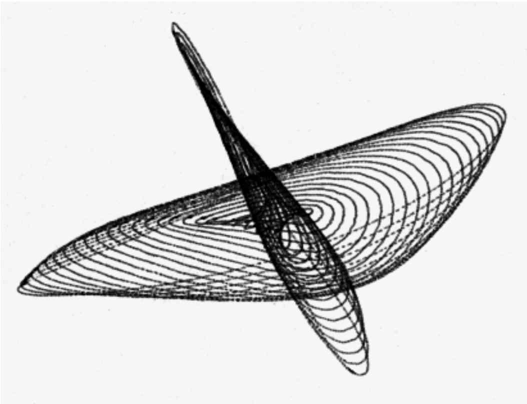


fig34

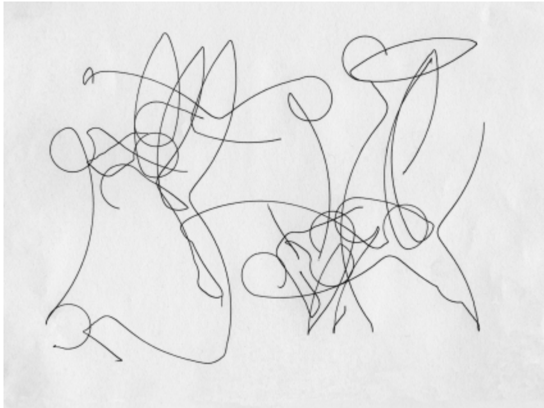


fig35

Fig34 is a drawing from 1961. Fig35 was made in 2008 where the machine and timer programming reached a point where the pen is sent to a locus and then draws an image. The contrast between the two shows the progress made over time. Photoshop enables colour to be added, allowing an extended range of images to be made; the results are limited only by the user's experience and imagination. At this stage the machines are acting as design tools able to carry out the artist's concept.

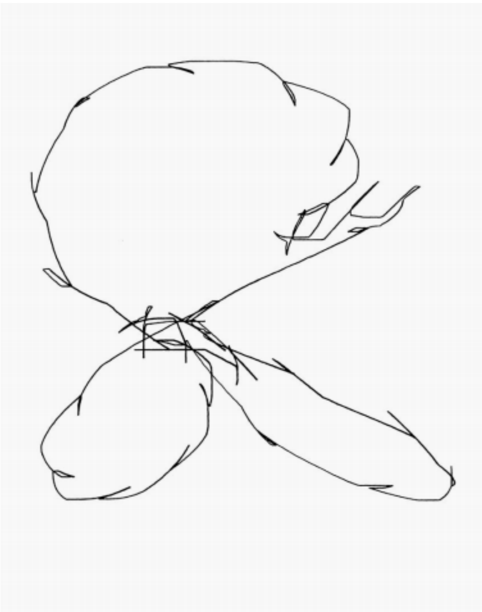


fig32

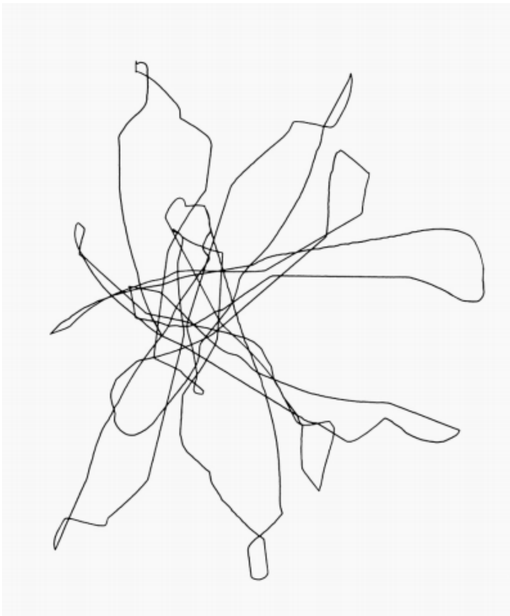


fig33

Fig32 is an NSEWsp drawing, fig33 by Turntable machine. The individual style of these two drawings is achieved by programming a complex concept. To reach this point reference was made to many previous drawings taking into account the machine and timer characteristics although in these machines their characteristics do not dictate the style. The large number of programming variables in the timers offers a wide scope for individual interpretations to be explored.

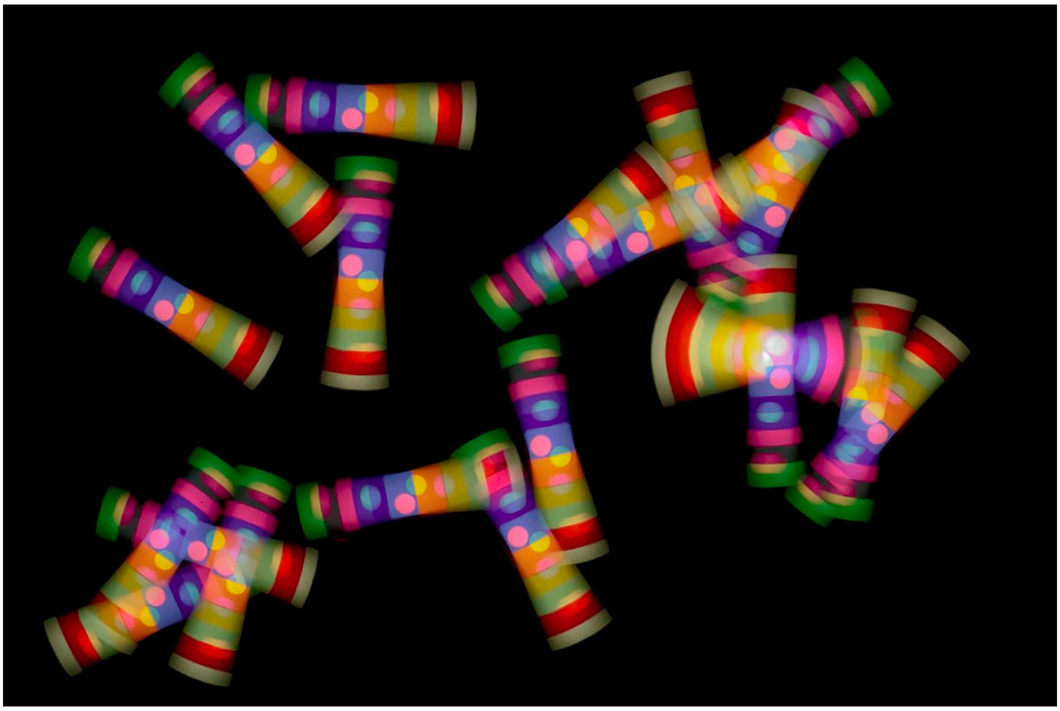


fig36

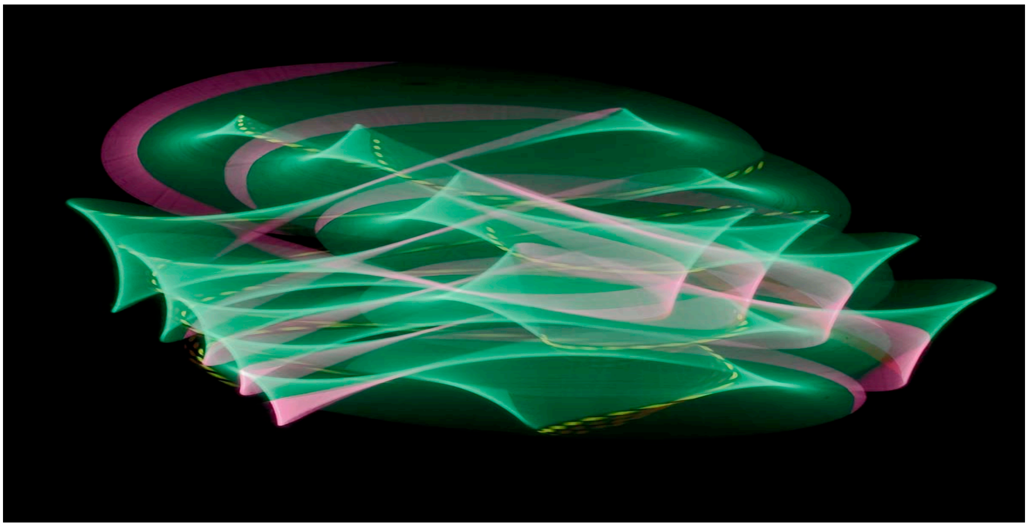


fig37

Future progress will be with light drawings as in figs 36 &37 above, reprising the photographic 'writing with light' notion. The principal message concerns the tonal three dimensional quality of the picture where the machine drawn element can be ignored. If this is achieved then significant conceptual progress may be claimed.

Further concepts are evident in the two drawings below, one from an early computer programme, the other exploring sinewaves. The computer image took as its theme the Kandinsky notion of basic shapes i.e. triangle, square and circle.

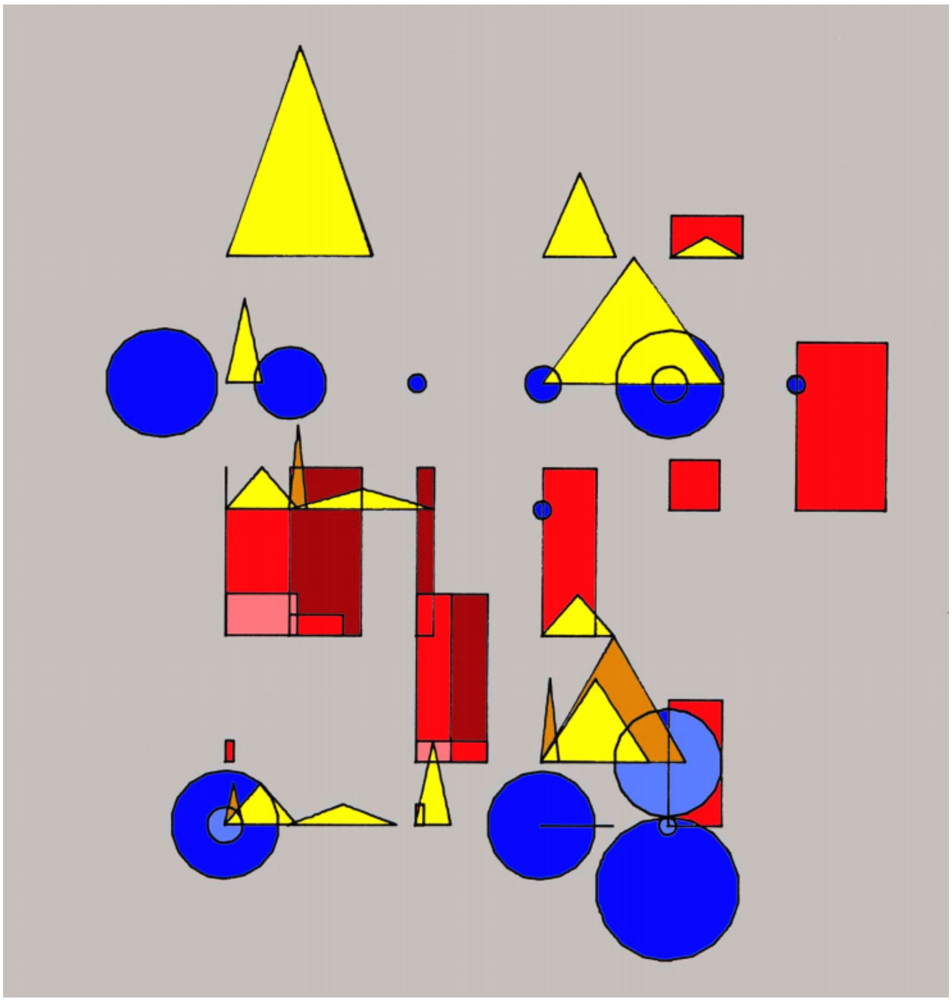


fig18 'Homage to Kandinsky' drawing programmed on Hewlett Packard computer, colour added later in Photoshop.

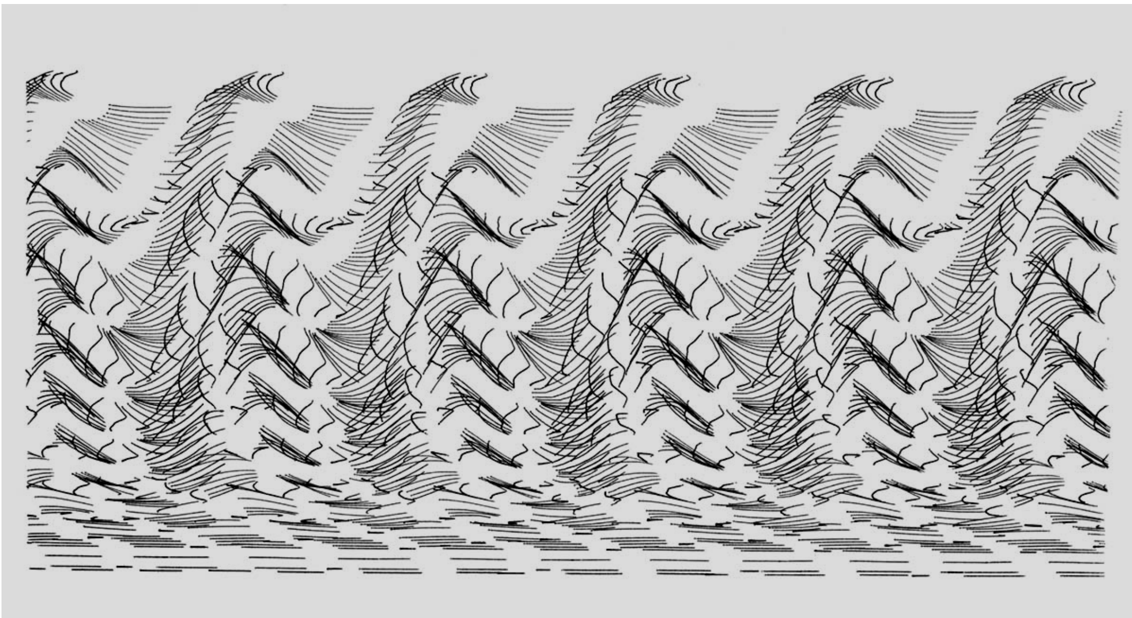


fig19 Sinewave with line break where the broken line interacts with the sine waveform.

Conceptual progress

The above implications, together with the graphic evidence produced, enable conceptual progress to be observed. The difference between simple ideas like the meccanograph drawings, progressing to conceptually richer points, draws a parallel to conventional hand drawing as ideas develop with experience.

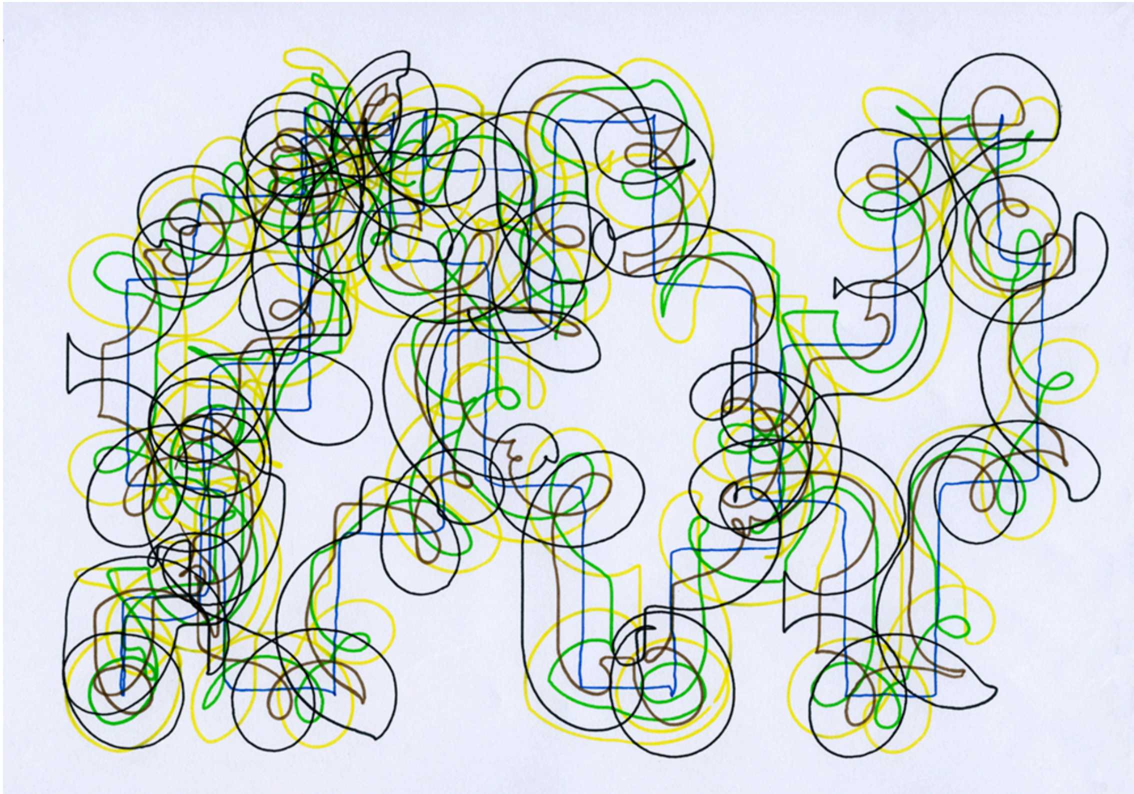


fig 38 A point concerning conceptual progress occurs in the above drawing. For some years it was hoped to design a unit where multiple pens could be used at once. Persistent design and recent engineering effort achieved this, expanding the range and effects possible with both the NSEW machine and some of the timers. Each time a machine or timer was rebuilt, the effort increased the range of drawings, the machines design appearance and reliability as well as making it easier to explain how ideas emerged.

Ideas do not always precede production. During design, building and testing new ideas or modifications frequently present themselves.

5. REFLECTIONS ON PROCESS - METHOD

Benefits

Explaining 'how things work' has tangible benefits. Externalising stimulates problem solving, often generating novel solutions which otherwise would not have been found. In developing seven machines and three timers, two machines and two timers were completely redesigned. Timer 4 was developed from scratch to extend the range; other items were significantly modified. During the two years of the research more improvements and innovations were made than in the previous ten years.

Purpose

The next question is whether the artist uses an existing machine or designs one for a specific purpose. The differences here are those of intent and practice. An existing machine restricts the user to a predetermined set of functions, only satisfactory when there is a close accord between the intent and the machine's characteristics. Whilst this implicit category includes cases where a computer is used to produce art works (using original or third party software) this study is restricted to simple electro-mechanical analogue devices. Given an existing area of research, and a machine designed to explore it, original and individual qualities are more likely to emerge.

Tools and machines

The essential differences between tools and machines in art practice needs to be defined. A tool is an extension of the hand, subject to hand and eye co-ordination. A brush or pencil is a tool in this respect. Some tools are also machines (if they are motor driven) but machine-tools still have to be guided by hand. A machine may be re-defined as 'A mechanical device which performs tasks without hand guidance; and can accept instructions permitting independent operation'. It is a significant step to delegate some control and 'decision making'[1] to a machine.

Programming

The presence or absence of programming divides analogue machines. Absence can manifest itself in chaotic drawings, except in the case of Harmonographs, where the physics of the pendulums dominates the programme. Machine drawings with programme control differ markedly. Determinism, carefully mixed with random elements, increases complexity taking drawings beyond simple symmetry and also offers the potential for repeatability. This brings any such machine into the category of 'design tool', able to explore a coherent set of ideas.

All seven machines are programmable; it is possible to record starting data and reset the characteristics.

[1]. *The term 'decision making' in this context implies choices or actions which would ordinarily be made by the artist's hand and eye but which are delegated to the machine.*

Programming is integral to the Meccanograph, Linkogram, Sinewave models; the Turntable machine can accept internal and external control. NSEWsp, NSEWch and Scribblogram plotters rely on external timers for their programming. The function of each timer is to allocate timed pulses to the machine motors. The timer designs explore different ways of sending instructions and incorporate measured amounts of pseudo-randomness. Each timer has three parts, time generator, forward and reverse switch and output selector. The order in which these operate governs the drawing character. Having repeatability puts the machines into the category of design tools. More learning has taken place in this area than any other; and helps separate Taitograph analogue machines from many others in the searches. Refer also to John Whitney's work, (Moritz,1997).

Pseudo-randomness

The presence of a random element, qualified by the adjective 'pseudo' to differentiate it from the correct mathematical term, is both controlled in extent; and welcomed as a full component of the creative process. Analogies may be drawn between randomness in machine drawings and hand produced art where accidents may be acceptable. Mechanical systems might possess random characteristics, by accident or from aspects of mechanical 'play'. Pseudo-randomness is deliberately introduced in Taitograph machines, by the mathematics of gear ratios, asymmetric geometry of linkages, cams and out-of-phase timing switches. The design process relies on the relationship of pseudo-randomness to determinism. See Kenneth Martin pg18. Its importance has emerged as one of the most significant aspects of my work.

The next points refer specifically to design features encountered in building the machines.

Designer's dilemma.

During construction, following a particular idea, another idea will present itself which appears preferable. The dilemma is whether to switch to the new or stay with the old. Both alternatives have been tried. The best strategy is to note the new thought but persevere with the original idea, taking it as near completion as possible. Following the first idea is beneficial and often generates insights applicable to the newer idea. There is also tendency for a first design solution, even when carried to completion, to be complicated rather than simple. To reach the most elegant answer a design has to be used. A simpler solution may arise but recognising the obvious can take time. Pursuing the process through this complexity barrier does pay dividends; the most difficult task is to reach a simple solution directly from the initial visualisation.

Data base of design solutions

After a long period of concentrated engineering work, a fund of solutions accumulates and speeds up future problem solving. In recent months, in response to the need to explain how machines work, new modifications have been done quickly, some in as little as half a day. This relates to earlier development work which was slow and labour intensive. What emerges is that experience has more to do with intensity of effort rather than duration. Reference to previous drawings is important. The differences are highlighted when looking at a number of images side by side referring to previous experience. Those with potential are readily apparent. Light images are viewed side by side on the computer screen.

Modifications

Overall planning of an idea involves an analysis of available modifications. Added to the colour, tone and line are the relative speeds of the X & Y axes, pen motion, resetting the start point, the choice of timer, and its settings. The problem is always one of too many alternatives. One solution can be an examination of past drawings, and from data records to plan small changes to one variable at a time. This dilemma is of course not confined to machine art, but the existence of repeatability and previous drawings can alleviate it. Additions and modifications to machine building is endemic. Eradicating faults or extending the range of one movement to another may be prompted by both negative and positive elements in the drawings. Some additions do not help but comparison with previous results usually offers improvements.

Line quality

Line quality is important because the cumulative effect of smooth lines in close proximity governs the success or otherwise of many drawings. Although a subjective issue, it has been a principal goal since machines were first conceived. There are two aspects which adversely effect line quality. One is mechanically induced judder which is easy to see. This is less of a problem now, as play has been engineered out and linkages reinforced. Lightweight linkages can suffer from stress flexing which causes unrelated ripple effects. The second results from pen and paper combination and the pen pressure. Counterweights provide pressure adjustment. Too much pressure causes judder and affects lines if they are subject to rapid movement. A further consideration is the magnification of line and paper texture during scanning when defects become pronounced. Photoshop allows easy fault eradication of artifacts but it is harder to replicate a drawn line.

Run time, when to stop a machine

Machine run time plays an important part in the appearance of the final drawing. Too little and the richness is absent; too much and subtleties are overwritten. Repeatability has to be weighed against time consuming resetting; it is preferable to rely on experience to judge the optimum time. Almost as important is choosing the timing of the pen lift to ensure that the last part of the line finishes at a satisfactory position. With light drawing, run time is set on the camera timer; the optimum times are between one and three minutes.

Possibility of colour work

The distribution and size of the closed shapes governs the potential for Photoshop colouring. Previous experience governs decisions; the drawing's overall characteristics generally suggest a particular treatment for after work. With light drawings, colour variation is planned, relying on the design of the colour wedges. Next, the programme to suit this has to be estimated. The results are seen in the camera L.C.D screen immediately after exposure, so that modifications and retakes can be made; making a case for mid- production evaluation. Final detail may be seen on the computer screen.

Tonality and colour in light images

Colour planning combines with the choice and implementation of the light-pen shape. This is often a slit-image, helping to create tonality (by the sweeping motion of its widest side) and where one colour overlaps another. The effect is to fill the black background with a balance of tone and colour; modifications are made until this is achieved. The choice of programme from the timer is a major influence on the movement and is adjusted first.

Recording light drawings

Particular attention was paid to extending the light drawings. More than 100 new light drawings were made to this end, including some on photographic paper. This research was particularly valuable; the range and variety of image was increased out of proportion to the time spent. The camera rig and other parts built specially for the research are shown below.

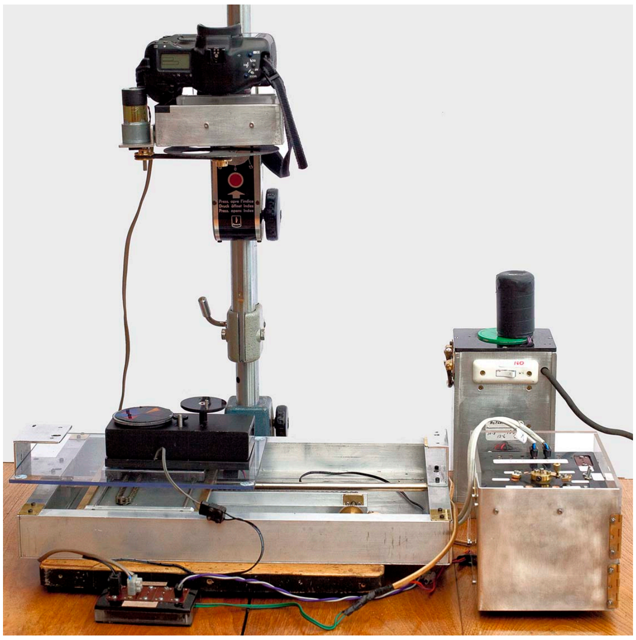


fig189

Camera rig, fig189, over the NSEWch machine with light unit, Timer 4 and power supply.

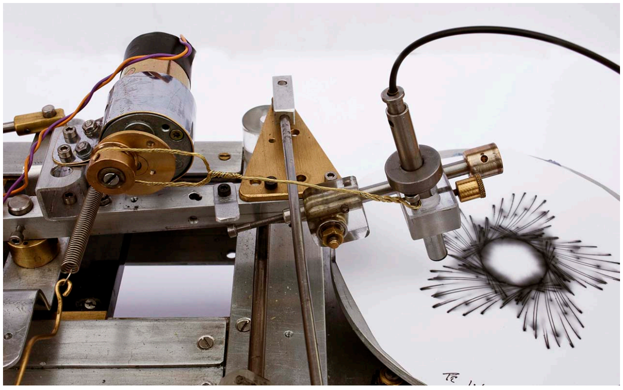


fig190 *fig191*

Fig190 shows the camera cradle made to sit on the platen of any machine with its electronic timer. Fig191 displays the light pen lift mechanism made for the Meccanograph.

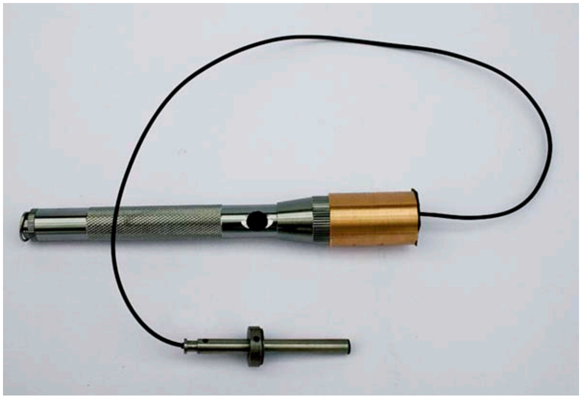


fig192

fig193

An LED torch and fibre optic lens system in fig192 provides a fine light point usable on any machine in conjunction with photographic paper, particularly in instances where the digital camera cannot be employed easily. Fig193 shows the size of the light point.

6. REFLECTIONS ON PROCESS - EVALUATION

Now that all machines and timers have been examined it might be helpful to reflect further on the thought processes involved in making art works with a machine and the questions which have arisen during the years of activity. These points may be seen as following on from the earlier discussion on the implications of using machines and adding to the observations offered during the individual machine descriptions.

Selection criteria

Evaluation and selection is a complex topic. Harold Cohen once claimed in a lecture (Cohen,1983) that all of his drawings were of equal merit. This debate was aired many times in the 20th c. by (Jean Arp ,2008) and (Sol de Witt,1969); I do not propose to air it further. Their stances are valid but for my part the choice is subjective. Subjectivity is qualified by me as the notion of ‘coherence’. The descriptor may apply if a drawing displays a 'rightness' when an intuitive evaluation is made. In my view judging generative images is a subjective process. Where pseudo-randomness exists in instructions, more chaotic than ordered results might be expected. However, when simple instructions produce complexity, more ‘coherent’ images emerge than might be expected. Turing (Turing,1952) made a particular study of chaotic systems which resolved to an ordered pattern. From potentially chaotic systems some pattern of order can emerge; a common theme in work by, Belousov (*Peterson,1998)* Mandlebrot (Mandlebrot,1982*)* and Kenneth Martin (Martin,1975*)*.

Aesthetic judgments

Images tend to be created in sets; a particular aspect of a machine is explored and a logical sequence of programming steps in the timer are followed. Particularly in the case of drawings, subject to Photoshop post-production work, it is necessary to establish criteria to use in the rank ordering. Sebastian Lera, (Lera,1980) in his RCA thesis on design decision-making, established that the first task was to generate alternative solutions to a design problem. The research employed in the machines and their drawings satisfies this proviso on a macro level whist the sets of images generated by a particular idea operate on the micro level. Lera's second point concerns the criteria for rank-ordering the alternatives so that the optimum solution could be selected. Lera's work was concerned with architectural design, where the criteria could be constructed on largely functional bases. In the case of drawings and light images, this functional criterion is not readily applicable to them. This section ends by listing the criteria employed to enable choices to be made. References to the original intent in creating the machines will figure in the discussion; an essential component of post-production evaluation.

Decision making and selection

In design activity, decision making and selection of alternative solutions are the basic elements. Throughout the descriptions of the machines below this is endemic and decisions are primarily engaged with functional issues; gears, linkages, circuits, movement modes and in some instances sculptural and ergonomic concerns. Aesthetic judgements become a subset of decision making once the drawings or light images are produced.

Gesture-like qualities

This is simply a descriptor for a particular artefact comparing a line to a ‘known’ effect and adding a further dimension to a range of line types created by the machine and timer combination. It should not be assumed that mimicking hand drawing is a primary motive. In graphic outputs in particular, programming sequences are often chosen which are most likely to create it. It occurs when line motion is interrupted by small and rapid changes in direction, caused by a motor reverse instruction or quick axis switching. These conditions are simple to produce in the timers. Large differences in X and Y times, combined with a specific relationship of sun and planet motors or pen motion tends to create gesture-like effects. Where this is important, a number of drawings plus trial and error produces progress. A significant step forward was evident when a pen-lift device, a revolving pen holder and Cartesian co-ordinate instructions were combined.

Third party response

Adding pseudo-randomness and delegating the outcome to the machine materially affects the art process. Curiosity driven `What if’ questions, always present in art process, are amplified. Referential observations arise such as *“I would not have* ***`thought’*** *of doing that”*. This creates what I term the 'third party effect'. Looking at a drawing as if it were done by another person and perhaps re-evaluating one's original intent is held to generate objectivity.

This might also raise speculation that the restrictive checks and balances, often imposed by the conscious mind, have been bypassed. The ego driven agenda,sometimes a problem for artists when judging their own work, has been minimised. This idea is a powerful attribute, particularly during mid-process evaluation. During the research it has proved helpful and stimulating, and is particularly applicable to the philosophical issues raised.

Many images shown above in **Concept** exemplify the *“I would not have thought of that”* reaction, illustrating the fine balance between idea, programming, and pseudo-random content, amplifying the element of unpredictability. They fall between blandness and chaos; governed by intuition and experience.

Machine or user?

Given that a machine is made to explore a particular topic, the question arises "Does the individuality rest with the machine or the user?" Clearly a custom built machine is individual to the designer, and its drawings may share this. The question then becomes "What is the significance of the user?" If the user is also the designer of the machine then they may justifiably claim that the individuality of the drawings is attributable to them.

However if another artist uses the machine to make drawings, is it possible that their style will show in the drawings? The answer to this may rest on the user's programming decisions and selections which could in some circumstances override the dominant effect of the machine's characteristics. Harold Cohen's machine drawings drawings displayed a similar style to his earlier hand made work but his programme was given 'knowledge' about drawing, something impossible with my programmes.

fig25

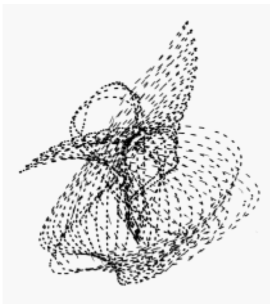


fig26

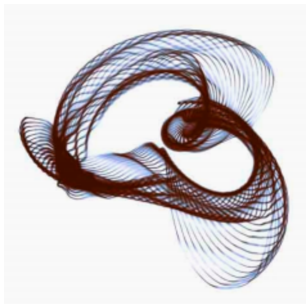


fig27

Three Linkogram drawings, two graphic, one photographic showing different settings. The Linkogram fig25 having a large number of alternative programming choices is more likely to offer scope for an individual style to emerge. Fig27 is a light drawing on photographic paper.

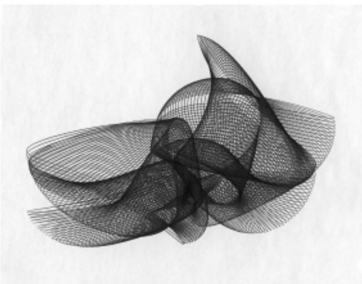


fig22

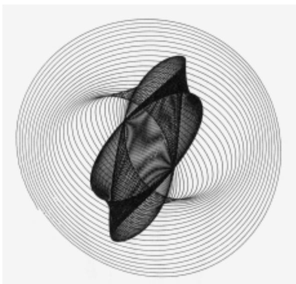


fig23

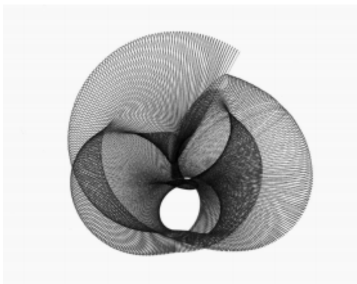
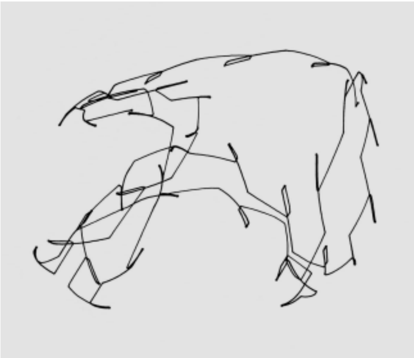


fig24

Fig23 is from a Harmonograph , figs22 & 24 are from the Linkogram. The shapes might differ but the style is governed more by the machines and less by the user.

Emergent patterns; machine or timer?

A peripheral issue in the selection process is the relative influence of the machine or timer. Each time a particular combination is used, drawings are often produced in sets. Whilst sets allow judgement of whether machine characteristics outweigh the timer's programme or vice versa, the issue is complicated by the variety of programming alternatives and the existence of overlap between some machines. The Meccanograph, Linkogram and Turntable exemplify this; all produce similar circular drawings where the lines are close and follow a deterministic path. Accordingly it does not seem that the nature of the individual machine need play a major role in the selective criteria.



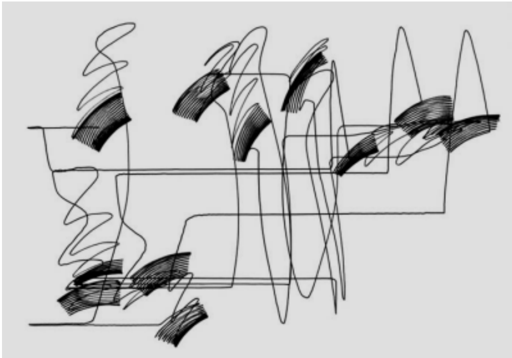


fig20 NSEWsp & fig21 Scribblogram; cases where the machine's characteristics do not dominate the style of drawing. The nature of the image stems more from the decisions made at the programming stage.

Can a machine drawing have individual style?

It would be reasonable to assume that individual style in a drawing would not survive the process of delegation the action to a machine. With hand drawn artworks, individual style is usually apparent. Recognisable traits are readily attributed to the personality of the artist and hand-eye co-ordination. This is absent from machine art. It is unlikely for instance that a harmonograph drawing done by one person, will be different from that of another. The machine's characteristics dominate the style. See images above.

Even when a more complex machine is programmed to make an art work, which involves a tenuous string of instructions this could still eradicate all signs of style. However the act of designing appears to create a 'decision pack' accessed during work and influences problem solving in the same way each time.

Does it alter the position when the artist designs the machine with a specific purpose and programmes it to follow a particular path? Of course when the resultant machine drawing is wholly random, no individual style is likely to exist. The position might be expected to change when programming is involved. Striking a fine balance between determinism and pseudo-randomness could allow individual characteristics to emerge producing a recognisable style.

This could well be a topic for another study but it is suspected that all the elements involved in the decision process could well combine to produce a recognisable style imprint. Harold Cohen's computer drawings (Cohen,1973) were held to be very similar to his hand drawn images.

Machines/drawings with individual style

Two exemplars, which seem to permit individuality to emerge are the NSEW and Turntable machines. Programming, combined with sun and planet mechanisms, was the defining advance, where I felt that a successful balance between mechanical characteristic, determinism and randomness was struck. Richness of drawing in this context means a line with gesture-like qualities, analogous to that of a hand drawing. Where light is employed, the richness of colour and added contribution of the light pen shape and intrinsic movement add further qualities.

In this context it is worth re-examining the set of images chosen to illustrate concepts in section **3** in addition to considering all the drawings in the book. If a drawing is seen to follow a specific concept then if could be proposed that this would confer some aspects of the artist's individuality.

Following on from questions of individual style it might help to include issues of perception as below and the contribution of colour choices

Reading tonal light drawings as photographs

Light drawings, particularly those with soft edges functioning as shadows, tend to be 'read' as conventional photographs. The eye and brain are tempted to adopt this approach. Noted some time ago, it provided motivation, influencing the design of light pen units and their employment. This has practical applications in drawing production as well as posing philosophical questions about perception which although interesting fall outside this books remit.

However when perception and colour are taken into account, the chances for recognisable individulal style to be perceived in a machine drawing might be improved. It would seem that these considerations are particularly significant when evaluating light drawings.

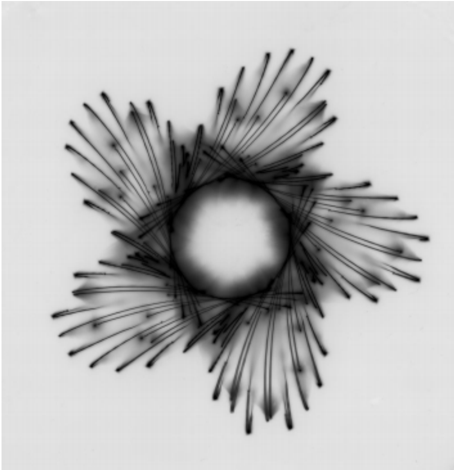


fig186

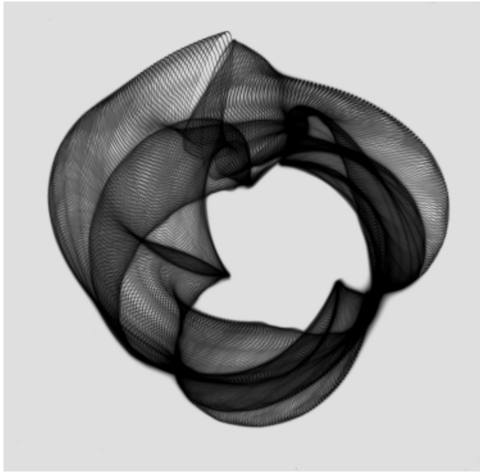


fig187

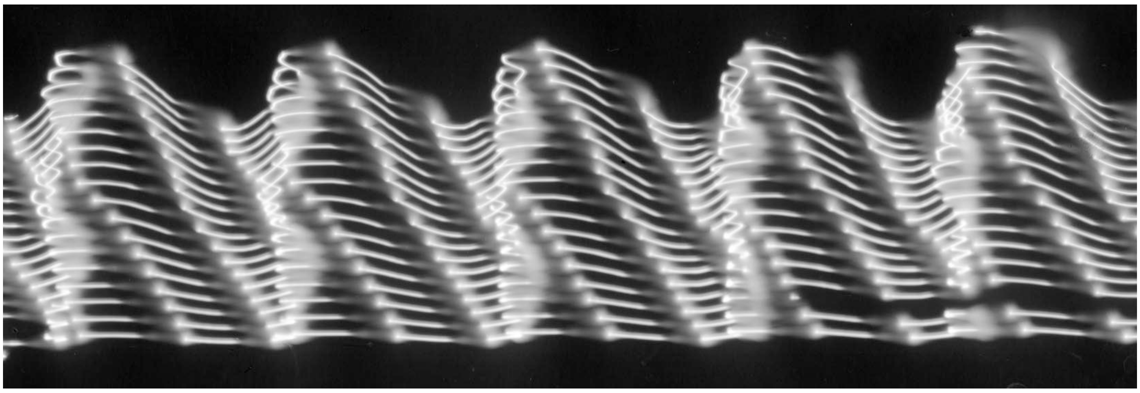


fig188

For the Meccanograph, fig186, Linkogram fig187 and Sinewave fig188 these images show some tonality which might cause them to be read as photographs; particularly in the case of the Sinewave image which has been inverted.

Colour and the meaning of marks

An obsession with colour created the major body of work, playing a crucial part in after-treatment of graphic images and is fundamental to light drawing. It is argued that the meaning of many Taitographs relies heavily on the use of colour and a significant measure of progress is attributable to it. Non-figurative linear work depends on the human propensity to derive meaning from lines or marks. When machines are instructed to draw lines this attribute begins to realise intent. It is held that adding colour takes the process a step further although it is accepted that this is open to debate. I have noticed that the response to colour varies more from viewer to viewer than the graphic qualities.

The final aspect regarding evaluation is perhaps to propose criteria to apply to judging drawings. The list below is derived from my own working methods and is offered in case it is useful.

Criteria
The criteria below are those I apply to drawings chosen for Photoshop after-work or for reiteration in the case of light images. Aesthetic values are an intrinsic part of my design strategy when trying to realise my original intent and purpose. The criteria may seem a bit tortuous as a list but in practice they seem almost subliminal. We are predisposed to make quick judgements; the list below has simply externalised my own intuitive actions:-

1. *Does the drawing exploit the original design intentions of the machine?*

2. *Is anything added to the canon of previous drawings?*

3. *Does the line quality reach a high standard of smoothness?*

4. *Has the run time produced a balance between richness and complexity?*

5. *Are there any gesture-like qualities of line evident?*

6. *Do the closed spaces offer a potential for Photoshop colour work?*

7. *With light images, does the tone or colour balance create a 3D feel?*

8. *Can improvement be made by modification and repetition?*

9. *Does the response occur, "I would not have thought of doing that." ?*

10. *Does the drawing suggest any new departure?*

Evaluation in art is controversial philosophical speculation beyond the remit of this book but the 'third party' notion is thought (by me) to be peculiar to delegating aspects of production control to a machine. It has been influential in my professional practice. Learning from machine intervention has been helpful in establishing a level of detachment. Whilst ultimate control does rest with the designer, welcoming unexpected outcomes is useful in the same way that artists accept serendipity.

Having examined the concepts, methods and evaluation of using machines to make art works is is hoped this will increase the understanding of the drawings, machines and timers which come next.

5 HOW THE MACHINES WORK

In the above section I have listed the aspects which have a bearing on the thinking process and the philosophical issues occurring when machines to make art works. Now I will describe each machine and timer mainly in operational terms.

Meccanograph-type* machine

The purpose of describing the Meccanograph-type, (*henceforth referred to as just Meccanograph), is that it is the simplest of all the machines and all other machines are derived from some of its basic principles. This particular machine came about as a result of research and debate into the Creighton machine (Rigge 1926) at a Bridges conference (Bridges 2006). However I had built similar machines with Meccano. It is referred to with the suffix *'–type'* as it has developed some way beyond the limited machine in the Meccano instruction book (Meccano,1930) although it solves the mechanical problems of achieving X and Y motion in the same way. The original solution was adopted being simple and elegant. Understanding this machine may show how other machines achieve their complexity; the same problems are addressed in different ways.

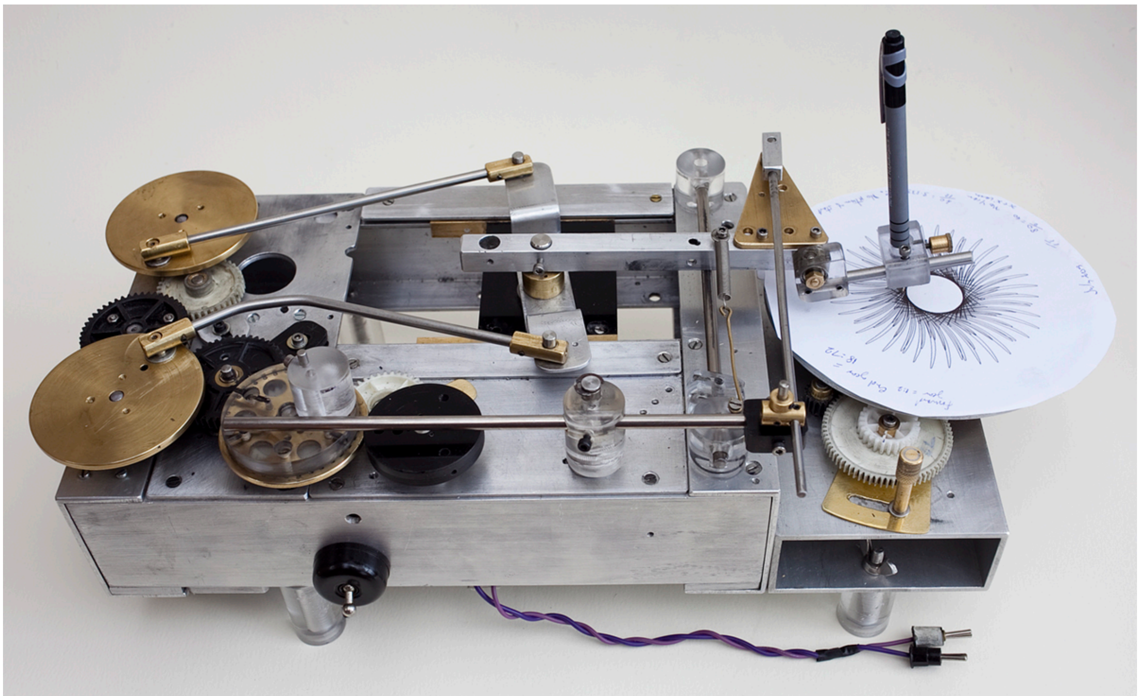


Fig39 Meccanograph machine. The brass wheels top left are X-axis cams and the lower two are the Y-axis cams. The X-axis carriage at the top, moves the pen arm east to west whilst the Y linkage moves it north to south. The turntable, and part of its gearbox, is seen on the lower right. This machine is shown in the schematic diagram below.

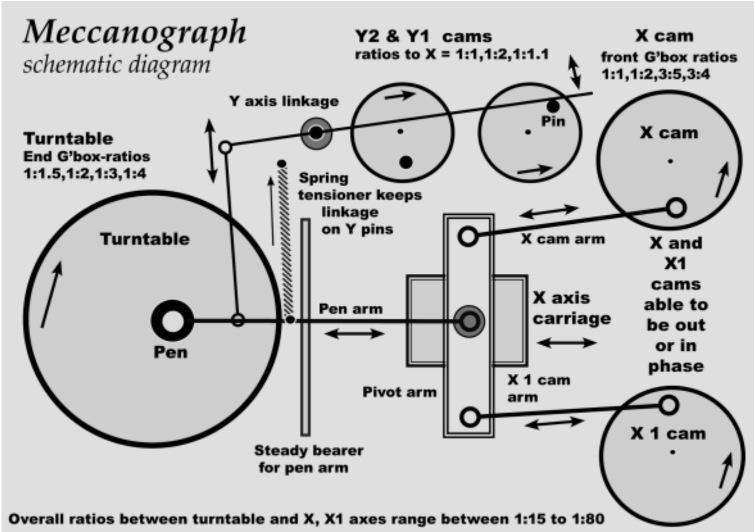


fig40

The components

There are three components to the Meccanograph machine, X:Y axis harmonic motion coupled to a turntable. This type of machine was outlined in a Meccano instruction book early on in the 20th c. and was in itself probably derived from earlier devices (Rigge,1926). Their primary function was to explore mathematical geometric figures; to define and establish ways of achieving perfect harmonic motion, where rotation was converted into reciprocating motion.

Underlying mathematics

In the current Meccanograph machine (see diagram above) a carriage is able to reciprocate along the X-axis. The carriage moves the pen arm left to right along the X-axis whilst the linkage to the Y cams at the top of the diagram moves the pen in the Y-axis. The pen draws onto the paper sited on the turntable. The drawing's shape is governed by the ratio of the X and Y axes to each other and to the speed of rotation of the turntable. For the drawing to work as a simple circular figure these ratios have to be whole numbers so that the drawing will return to its starting point. Most drawings resembled ‘flower type images’ where the petals were drawn as a series of loops. For instance if the turntable made 1 revolution to 20 of the X carriage then there would be 20 petals. If the Y ratio were the same as the X ratio then the loops would be either full circles, ovals or lines with all variations possible in between depending on the phase relationship between them. The form of the loop is governed by the ratio and phase relationship of the X and Y settings. If the X and Y are in phase, i.e. they are both at 12 o’clock, then the petal loop would be a circle, whilst if the X axis is at ‘12’ and the Y at ‘6’ then the petal loop would be almost a straight line. Where the Y-axis operates at a faster rate than the X-axis, e.g. 2x, then the loops would be in a figure of 8 shape.

The turntable usually operates at a lower frequency than the X-axis, somewhere between 10 and 100. The basic ratio chosen for the machine shown is 1:36

although this is variable by means of simple gearboxes. Multiples of 12 are useful as 12 is divisible by 1,2,3,4, and 6 which allows a greater range of image to be drawn. Unlike the original Meccanograph machine, this has the same system as used in the Linkogram where the amplitude of the X-axis cam varies between zero and maximum.

In the Linkogram this 'organic' growth and decay is very slow but in the Meccanograph machine it is set to go through the full cycle from zero to maximum in 12 revolutions. This means that the drawing will return to its starting point in a small number of turntable revolutions depending on the exact X: turntable ratio chosen. Return to the starting point is a characteristic usually sought in this type of drawing.

Salient features of the Meccanograph drawings

To make sense of the drawings the salient features are outlined and their relative importance to each machine as its aims are discussed. It important to recognise any limitations or constraints which exist due to the nature of the machine chosen. A preoccupation of this study is to address aspects of art process where the intrinsic quality of the drawings warrants it. Some of the simpler machines and their output are unable to raise significant points of philosophical interest. This distinction will form a part of the examination.

The illustrations below show the variation in images, selected out of the large number available. They aim to highlight variations produced by one simple change to the programming. Programming in this case is adjusting the ratio of the X:Y to turntable. The Meccanograph machine is a very simple device, albeit built with precision. Precision is very important; any ripple in the line quality has to be eliminated. In most cases the line must return exactly to the origin point if the aesthetic character is to be maintained. The above specifications are essential to this design; others may not share the same priorities. In more complex freer machines, line accuracy does not necessarily have to be as precise. The relevance of this is discussed below.

The important factors in a Meccanograph drawing are easy to list. All images are circular and depend for their quality on the accurate repetition of shapes. Depending on the complexity of the shapes, secondary patterns of line will occur as a product of the symmetrical repetition. It may even be possible, in some images, to display a three dimensional effect. Whilst there a large number of subtle variations, from the interplay of the turntable to X:Y ratio, many satisfactory images are those where the numbers employed are low and where one may divide into the other. For example if the turntable revolves 48 times slower than the X axis then the Y axis rate would need to be in a simple ratio to the X rate, i.e.

1:1 or 1:2, or else it would need to divide into 48 e.g 1:4 would divide 12 times whilst at 1:5 would not. For the drawing to return to a point of origin it would take longer i.e. 48 x 5 = 240. This means that the turntable would have to make 240 revolutions and by that time the drawing is likely to have too much detail.

Symmetry is an unavoidable feature of these drawings, and notwithstanding any aesthetic reservations about symmetry (mine), the precision and textural complexity produces attractive images as generations of ornamental turners (Holtzapffel,1898) have demonstrated. The purpose of the Meccanograph machine is to show how a simple machine can help in the design of more complex ones like the NSEWsp. It is seen as a means to an end, the first step on this journey being the extensions of drawing facility embodied in both the Linkogram and the Turntable machines where the basic harmonic motions have been explored in greater depth. More interesting drawings are obtained from the NSEW, Sinewave and Scribblogram machines. Further richness is available when the machines draw with a light pen onto a digital sensor. Tone and colour extend of possibilities when added to line alone.

Limitations of the Meccanograph machine

Finally, perhaps the major limitation of the above Meccanograph machine is that there is scant opportunity to examine notions of intent, which may then come into play during the evaluation of the images. This is the aim of the study, where the description of the machine development has the potential to raise philosophical questions about art process. It is hoped to demonstrate a progression towards this goal as the descriptions of each machine and the history of its development unfolds. The Meccanograph machine thus acts as a foundation on which the examination of other machines may rest.

Meccanograph drawings

Each drawing below has a caption describing the settings and the relationship to the variables. There are three variables, the fixed or variable amplitude X/X1 axes , the ratios of the Y1 and Y2 axes to each other and the X axis and the varying speed of turntable with its ratios to the X/X1 and Y1/Y2 axes. Whole number relationships produce the simplest and most symmetrical images. Phase relationship only occurs in the X axis; the speed difference between X and X1 is a large whole number, returning to its start position in 12 revolutions. See caption for fig67 p......

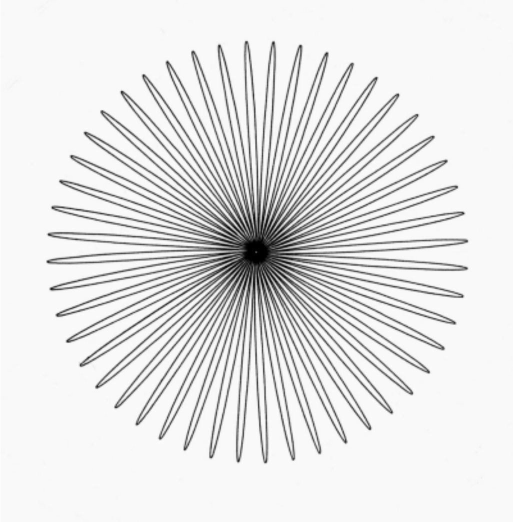


fig41

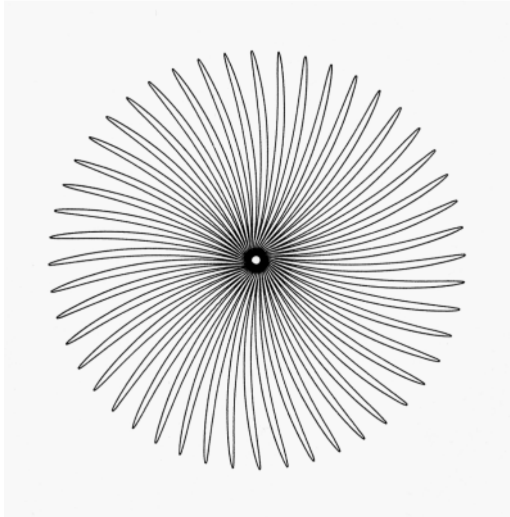


fig42

The left hand drawing fig41 is the simplest setting, with the X-axis (no varying amplitude) and turntable in operation. The turntable:X ratio =1:48 producing 48 loops. The inclusion of the Y linkage in the right hand image fig 42 causes the loops to 'bend'.

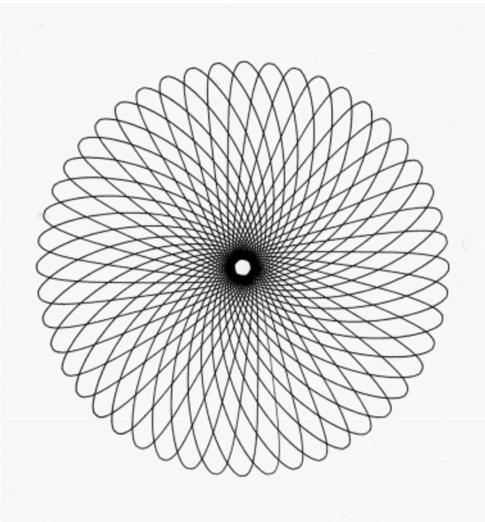


Fig43

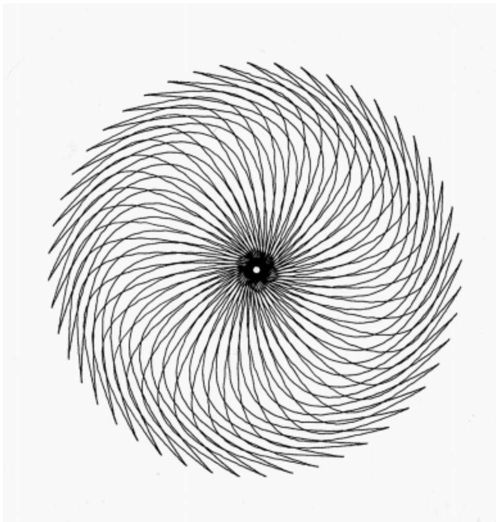


fig44

Fig43 has both the X and Y cams in operation with the X at 1:48, with the turntable and the X cam in phase with the Y cam; in clock face terms both are at 12 o'clock. In fig44 the phase is opposite i.e. at 12 and 6 o'clock respectively.

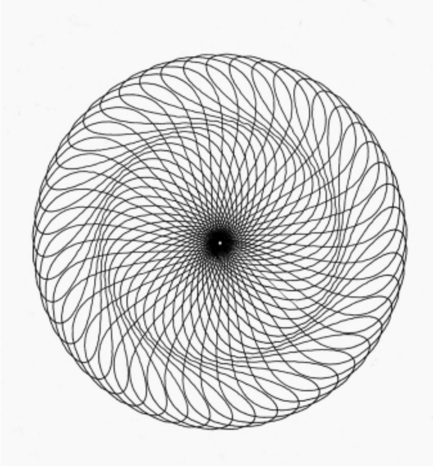


fig45

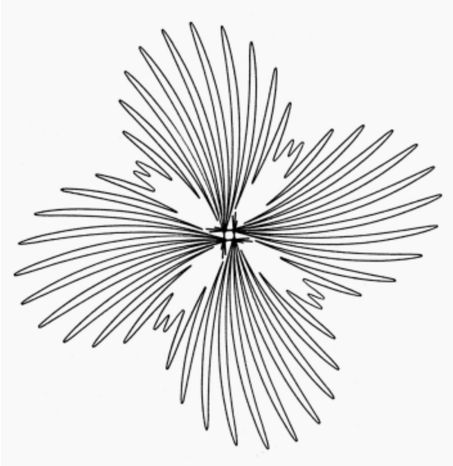


fig46

In fig45 the X and Y2 cams draw an 's' shape due to the Y2 cam rotating at twice the speed. In fig46, X: X1 is out of phase, producing varying amplitude. The number of loop sets depends on the turntable:X ratio and if the turntable speed divides by 12. The turntable:X ratio =48/12 making four loop sets.

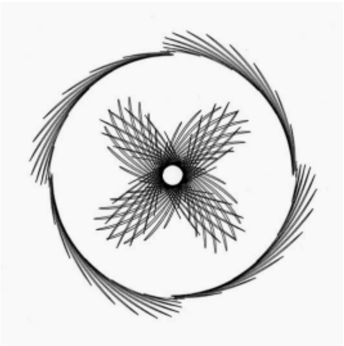


fig 47

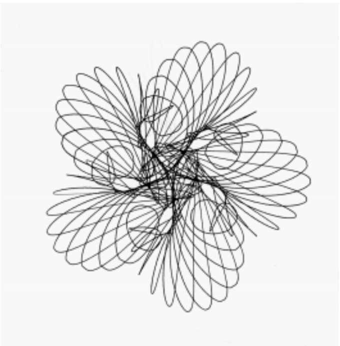


fig 48

fig 49

In fig47 are two drawings at the same setting. Only the pen was in a different position on the turntable. Fig 48 has Y1 in phase with X, which was set to varying amplitude. In fig49 the Y1:X ratio is 44:40 instead of 1:1, with the turntable at 1:60.

In the last drawing fig 49 the machine was stopped before it returned to its origin as it would have taken 10x longer for this to happen and the drawing would have filled in producing too much detail. If the ratios get too far beyond a whole number relationship, the drawing exhibits a chaotic character. It is a matter of subjective judgement when to stop the drawing.

Conclusion

Further pictures below show some of the post drawing possibilities to which the Meccanograph drawings may lend themselves. They go little further than decorative statements compared to other images and this is seen as a limitation, attributable to the unavoidable symmetry of the original drawings.

Using light

Recent work with a light pen drawing onto photographic paper where the light can also be lifted in and out of focus has been encouraging. The effect of this has added tone to line and gone a little way towards the goal of making light drawings which are more photograph than line drawing.

There are commercial applications for these images as design motifs in textile and other areas giving them a place in a broad professional portfolio. This machine represents the simplest starting point. Other machines build on this adding complexity and extending the range of machine drawing. Going from the simple and direct to the complex and esoteric is seen as a supportable stance and is common to many areas of art and design practice.

Extended Meccanograph images.

Four graphic drawings and two light pen images on photographic paper are shown below. The best use of the Meccanograph might be to make drawings for afterwork in Photoshop or when using a light pen on photographic paper. This creates a different line quality particularly when the pen is lifted in and out of focus as in the last two images below.

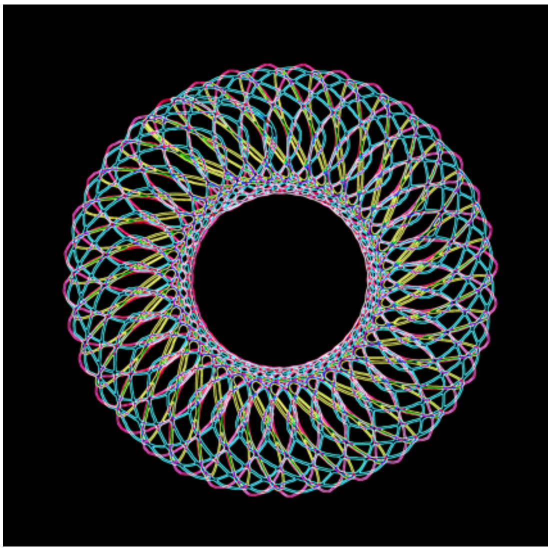


fig50

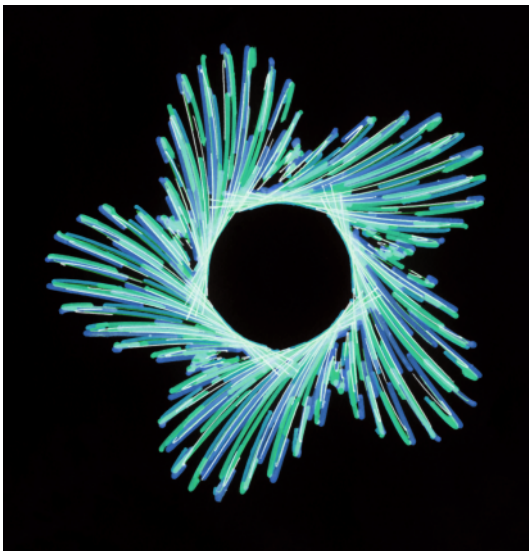


fig51

Figs 50 & 51are pen drawings where a number of passes were made with different colours. The precision of the machine allows this to be done. Images inverted in Photoshop.

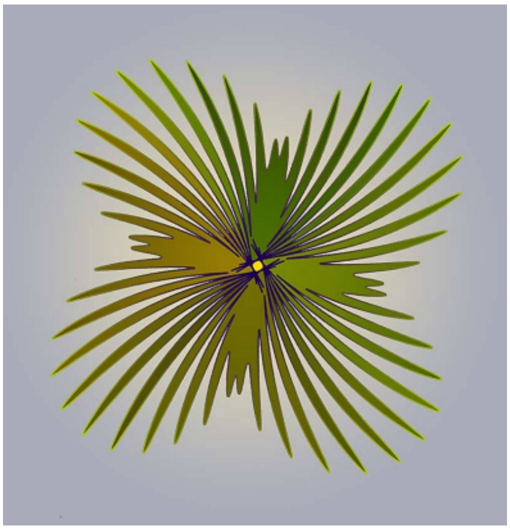


fig52

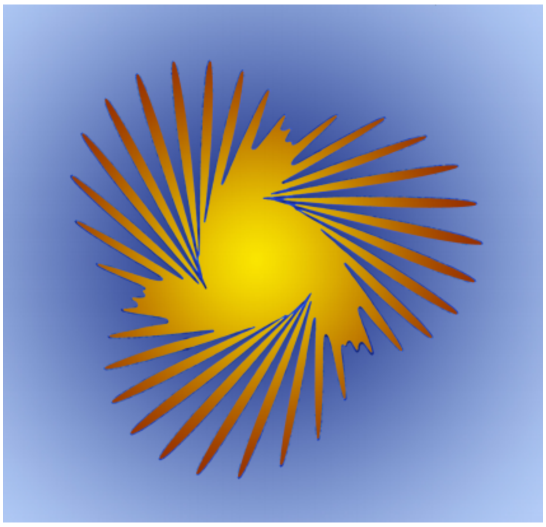


fig53

Figs 52 & 53 exploit the variable amplitude of the X axis with colour gradation added in Photoshop. The number of loops is readily altered.

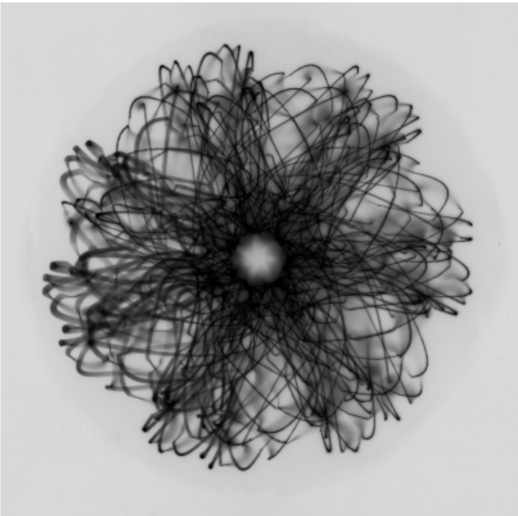


fig54

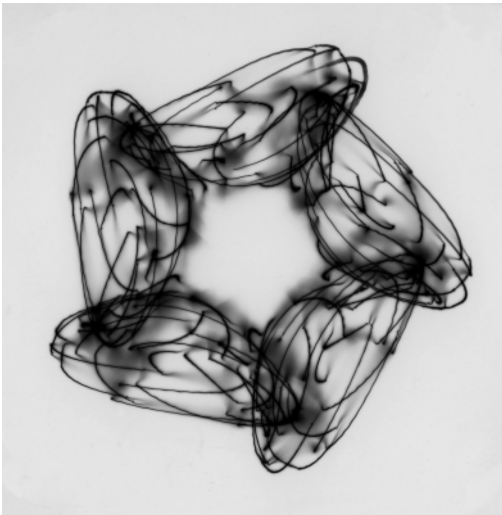


fig55

Figs 54 & 55 are light pen images where a Y axis movement was added to the X axis and the light pen lifted out of focus to create tonality to add to the line.

Linkogram

In 1958 I designed a cam and linkage system to reproduce the harmonic motion of a Harmonograph to dispense with pendulums. Their space, weight and problems with replicating the exact starting point for the swing was seen as a disadvantage. This particular solution to the problems of amplitude decay, frequency and phase control was not noted in any other machines from the searches undertaken in the historical survey.

The machine was made out of Meccano and measured less than 6 inches square, unlike a Harmonograph which often called for a pendulum measuring 39 inches long (frequency = 1sec) and needed a rectangular area of two by three feet of space. The Meccano machine was able to produce a range of figures but had severe backlash problems (excess play in bearings and linkages) which caused the line quality to be very poor.

The system relied on two sets of 3 inch pulley wheels coupled by a rubber belt drive to drive the X and Y axes respectively. Two pulleys were needed for each axis as they were to provide a diminishing amplitude by gradually getting out of phase with each other. This diminishing amplitude was created by belt coupled pulleys which creep during rotation resulting in the two wheels getting out of phase with each other after a number of revolutions.

The 3 inch pulleys got out of phase sufficiently to mimic the running down of the pendulum; when they were both at the 12 o'clock position their cams moved the link arm to the maximum rise and fall whilst when they were in opposite phase i.e. at 12 and 6 o'clock, there was no movement at the centre point on the linkage. This system is shown in the schematic diagram of the Linkogram below.

The Linkogram went through many stages of development. Three close ups are shown in the drawings **A1**, **D1** and **H1** on p61 show line quality whilst design improvements to the engineering are on p53-54. Its design led to all the other machines in the study.

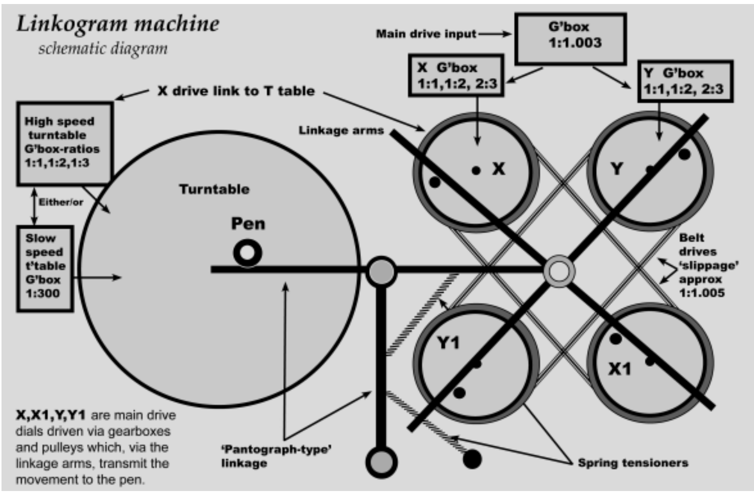


fig56

The early design is from around 1998 before rebuilding with other materials. The same design was adopted for the second machine shown, which although a wooden body 'prototype looking 'device, did have bronze bearings set into the frame; achieving a level of precision far beyond the level possible on the Meccano model. The pulleys were much larger, turned from Perspex, and the linkage was able to run parallel to the turntable whereas before it had been seated on a gimbal, which meant that it did not move parallel to the turntable. The X to Y gearbox had a closer ratio than with the Meccano gears, and was in the range 1:1.0025-1:1.005. All the improvements contributed to the precision and line quality; in addition a light unit was created which enabled the machine to draw with a light pen onto photographic paper.

The last Meccano machine and the first example, of the permanent machines are shown below. (Meccano machines were always dismantled to rebuild the next). The non meccano machine was a fragmented design, with bits added on here and there and given that the aim was to make machines having sculptural qualities this design was a non-starter. However it worked well and provided a solution to the attainment of high line quality.

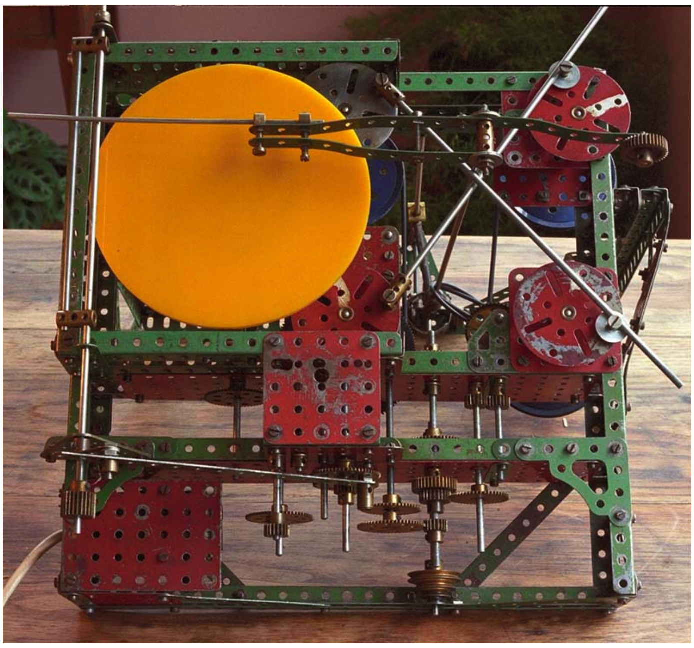


fig57

The last example of many Meccano Linkogram designs.

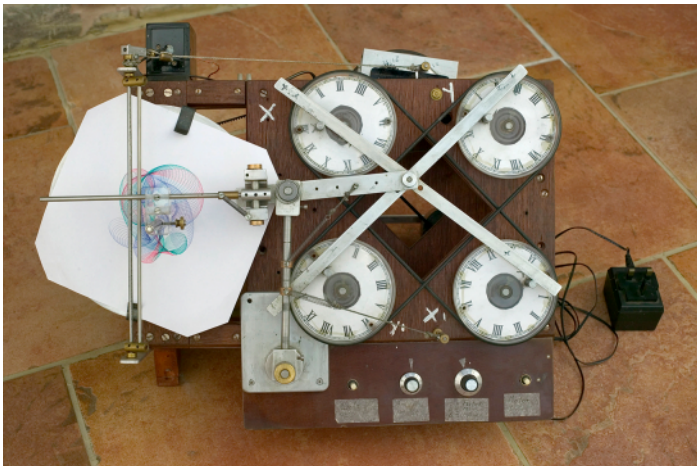


fig58

Linkogram Mk I wooden frame, 'Heath Robinson' in looks but with precision action. The radial linkage, connecting the arm centres to the pen, can be seen more clearly here than in fig81 where it is masked by the turntable. Also shown in the schematic diagram p38.

The similarities in design between the Meccano and the wooden frame machine can be seen in the two illustrations. On the top left hand side the small black unit is the light box holding a bulb feeding a fibre optic lead (not visible). This light unit has recently been redesigned with an LED light source

The final and current design was made in an attempt to rebuild in a modular proportion of 2:3 in 10mm Polycarbonate. Larger aluminium pulley wheels were turned to +/- 1/1000th in. accuracy to allow the utmost precision in phase and amplitude progression. The pulley wheels were sited inboard for both convenience and cosmetic reasons so that only the cams and linkages were external. All the gear ratio controls were sited at the back of the machine and again the access was easy and simple to operate.

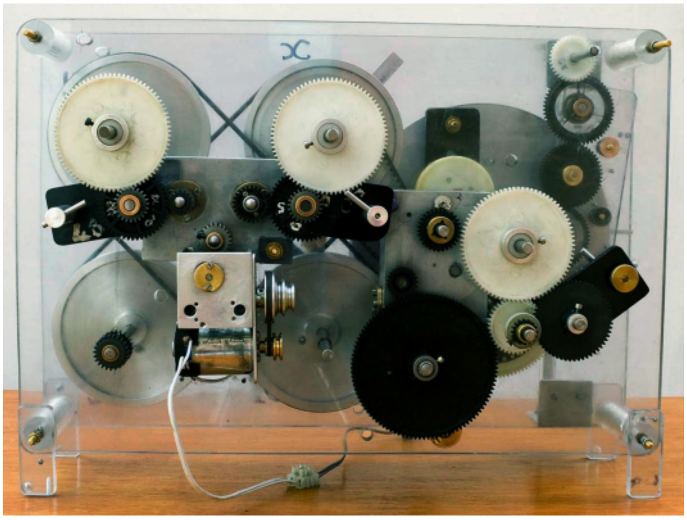


fig59
Rear of Linkogram Mk II showing adjustable gear ratios.

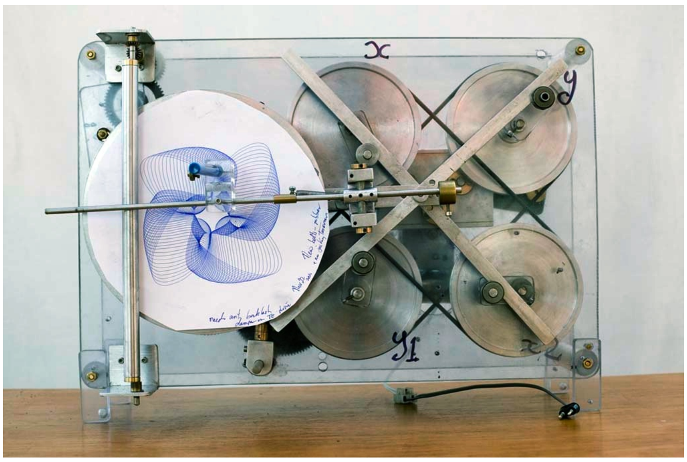


fig60

The Linkogram Mk II machine, front view, designed as a modular shape to be simple and elegant, in use for some time but linkage was modified during the research, see fig61.

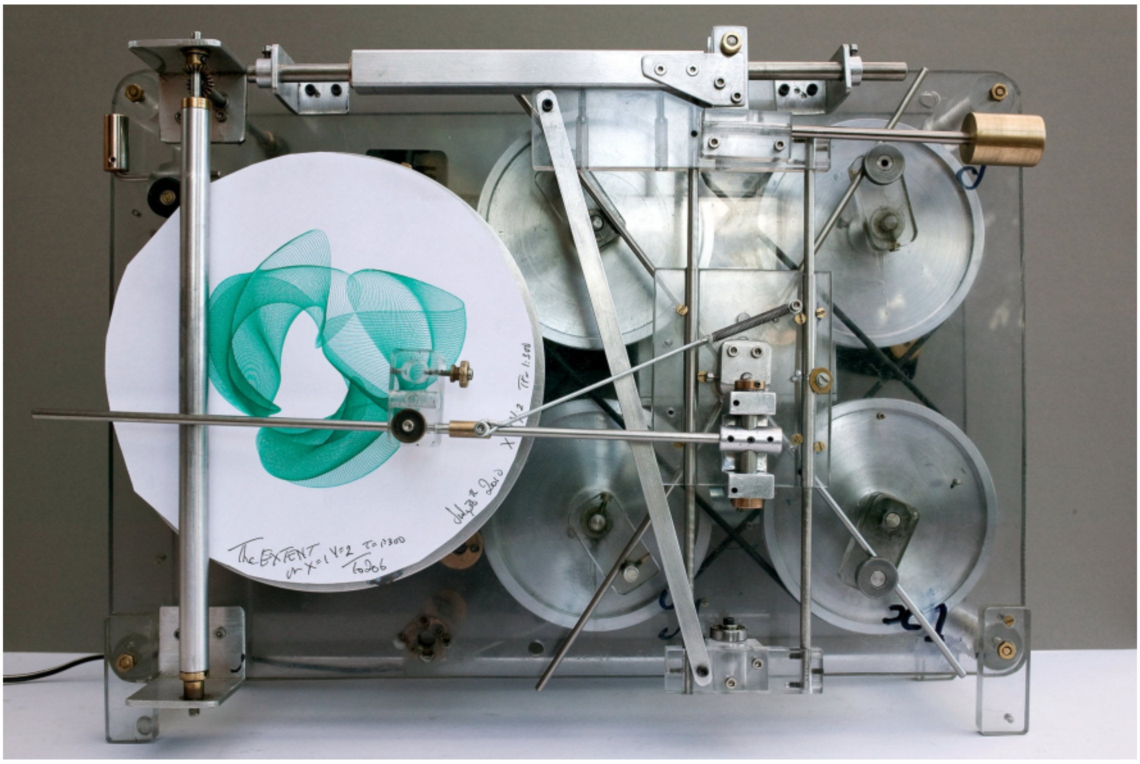


fig61
In Linkogram Mk lll the figure shape is created at the central point between two arms and four wheels. A radial linkage, best seen in fig60, transmits the figure to the pen but distorts it. In fig61, the collection mechanism, a parallel linkage, imparts no distortion as there is no radius. Extra weights and structures seen are to eliminate any tendency to line ripple.

The benefit of these modifications was that the perfect Lissajous figures created by the X and Y axes could be drawn accurately onto the turntable platen.

The object of the rebuild was also to create a machine with sculptural qualities. Having reached a high standard of mechanical accuracy which approached the Harmonograph level of line quality, all the attention could be directed at the drawing output. A high degree of repeatability was now delivered by the mechanics and this, combined with the pen lift effect, was able to extend the range of drawings as the machine functioned as a reliable and versatile design tool. During the research it was found that the linkage, which transmitted the information to the pen, was distorting the drawing. A new 'sculptural' design is shown in fig61.

Design and rebuild activity has a beneficial knock on effect on other machines encouraging more ambitious projects and taking advantage of the increase in engineering skills. These skills were acquired in the design and construction of precision medium format super-wide angle cameras for architectural work. The association of one creative activity with another makes the point that art and design work does not occur in a watertight compartment but one activity feeds into another and is part of a common approach and mindset. Below are some examples of Linkogram drawings showing post unmodified and post drawing developments.

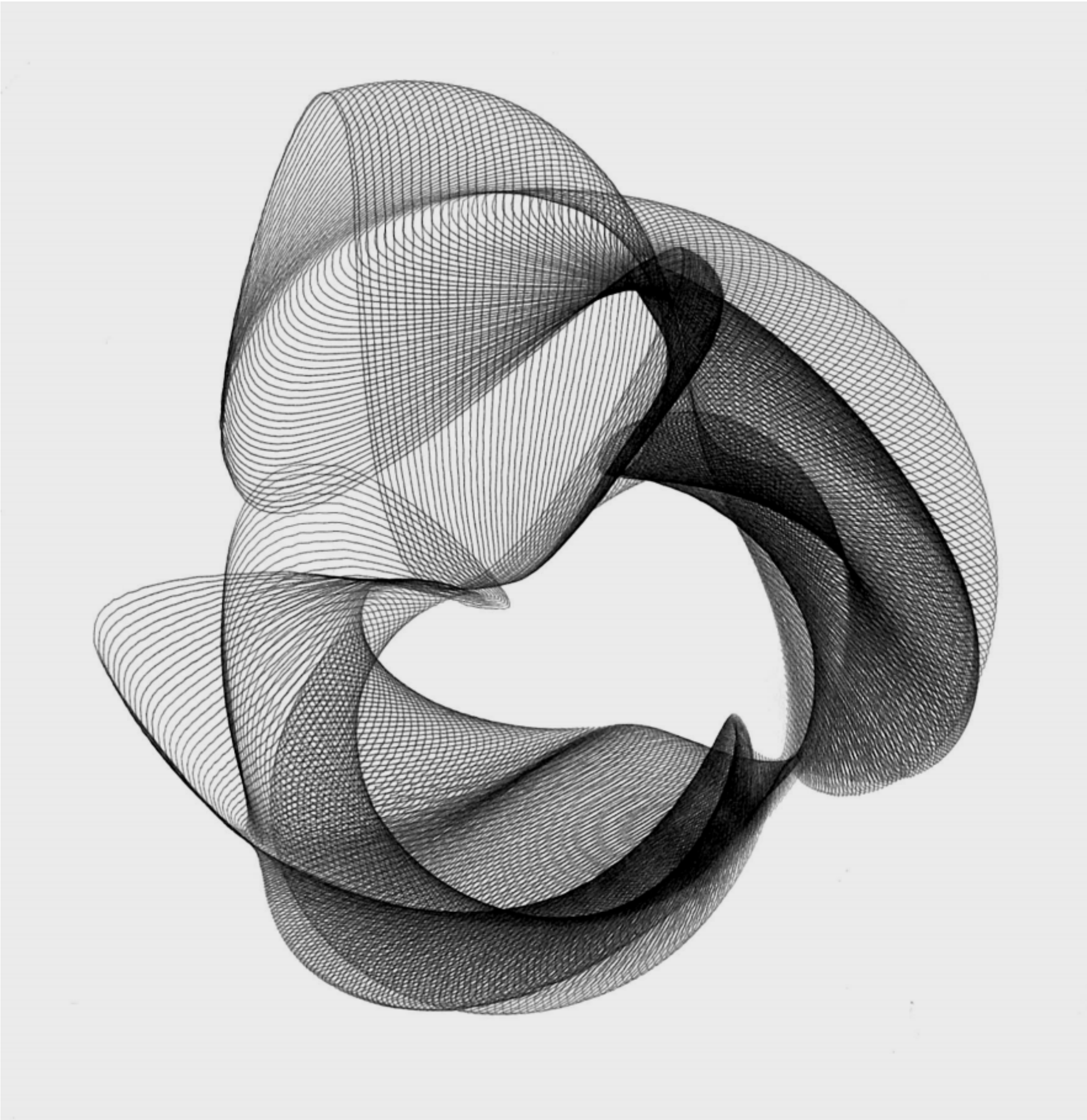


Fig62 shows the perfect Lissajous X=1,Y=2 figure which morphs as the turntable revolves. It is a consequence of the linkage modifications described in the fig61 caption above.

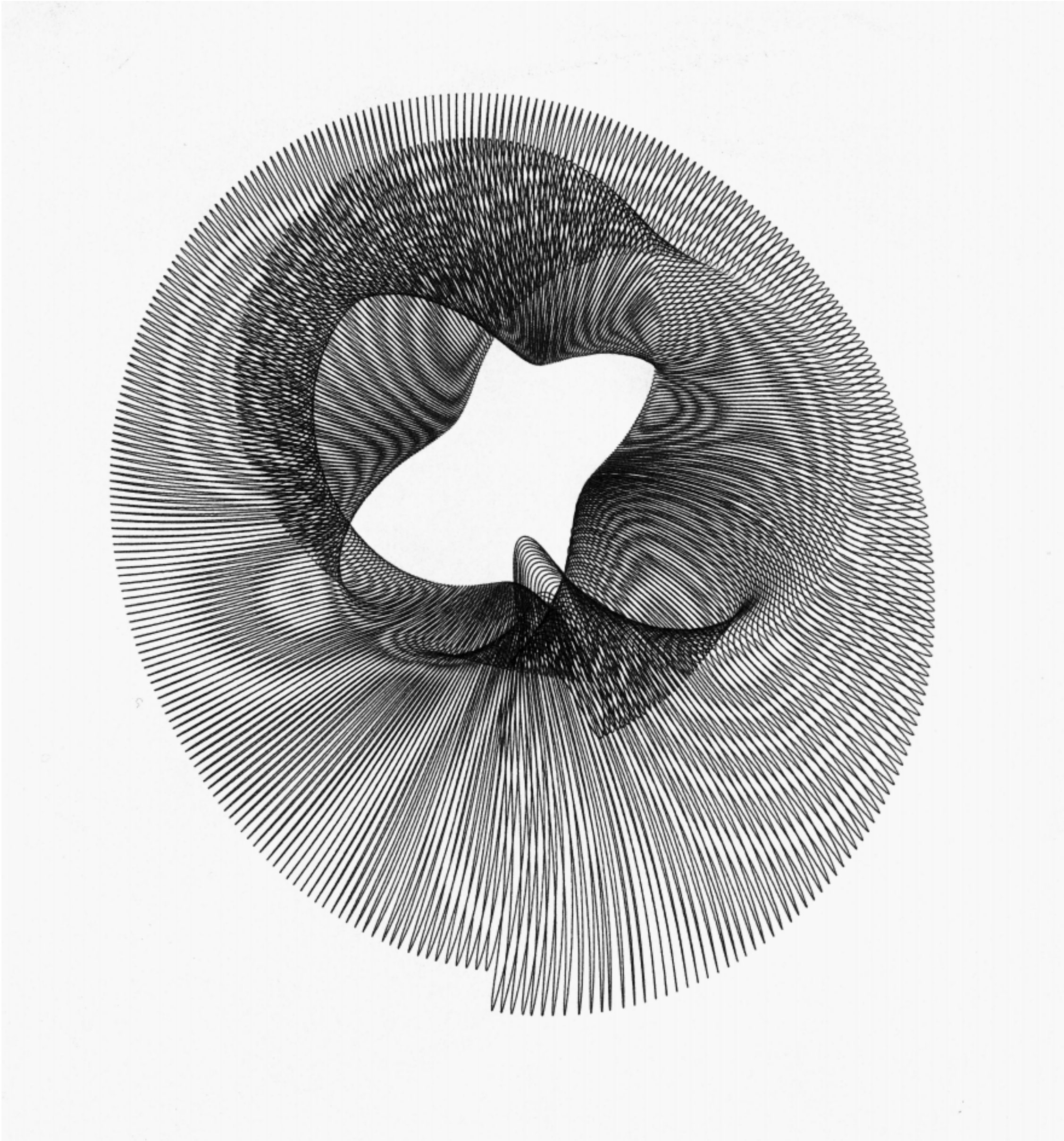


fig 63

This image is shown large to display fine detail. This drawing is a typical Linkogram image showing the accuracy and complexity. Line quality is limited by the pen and paper used; they govern line smoothness. The line quality in this example approaches that of a Harmonograph Close up scans of images are shown below to illustrate the variety of line when magnified.

Fig 61settings were X=2, Y=4 with the turntable speed slow at 1:300. The start point was set to draw a basic circle and the closeness of the lines created a moiré effect. The complexity stems not from the setting, which is a very simple ratio, but from the time the machine ran and the turntable slow speed which allowed a basic shape to go through the phase change modifications. Interline spacing is particularly important for the best results and when close creates moiré effects.

These changes in the phase of the X and Y axes together with the growth and decay characteristics, slowly altered the form created by the X to Y ratio. The phase changes are created by both the X:Y gearbox together with the slippage of the large aluminium wheels. The ratio of these is approximately 1:1.003 (see diagram p53). The turntable's function here was only to progress the X:Y shapes and did not contribute to the shape of the image. The drawing was stopped when the turntable had completed one full circle.

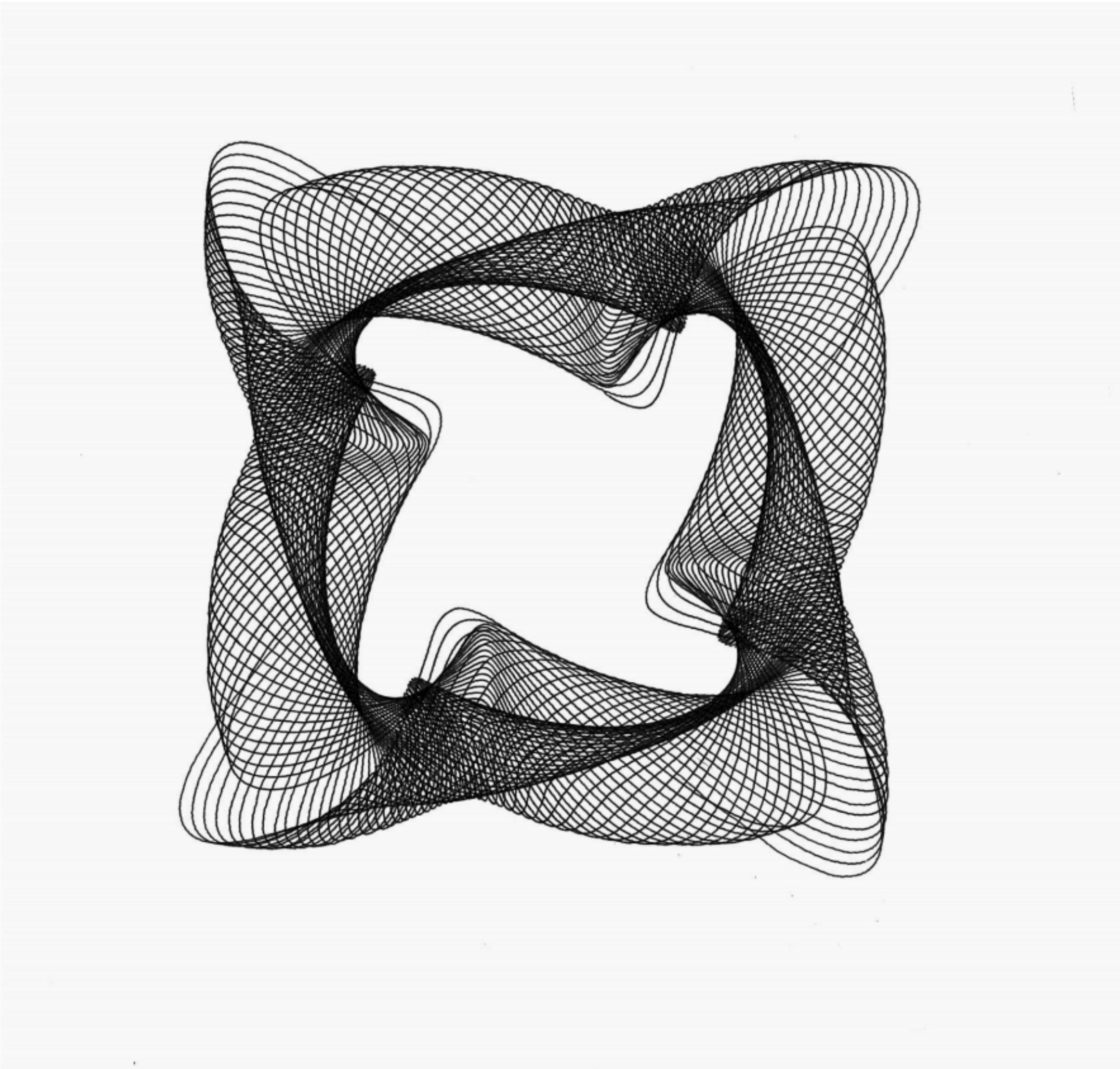


fig 64

Settings in fig64 above are X=2, Y=3,Turntable = 4. The turntable created four loops; the X:Y ratio created the shape, modified by phase changes as the drawing progressed. This is the second Linkogram variation; the turntable ratio contributed to the overall shape.

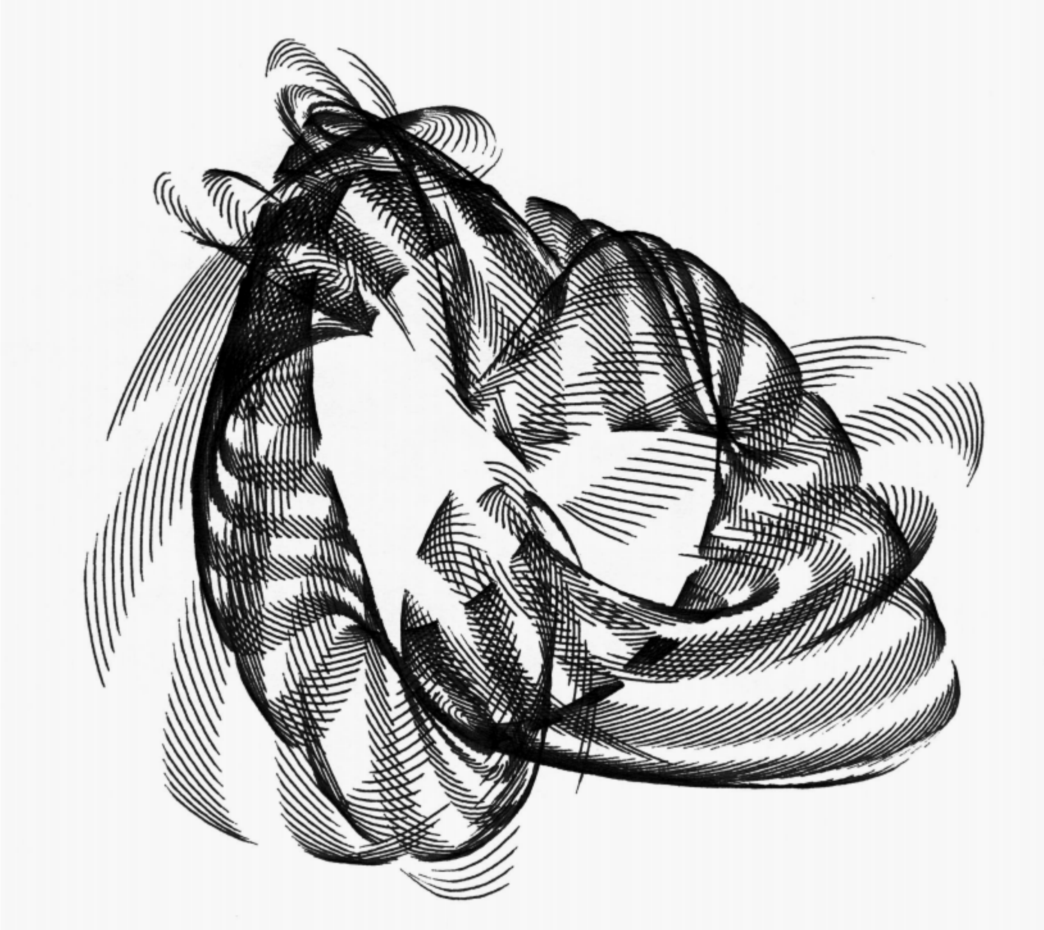
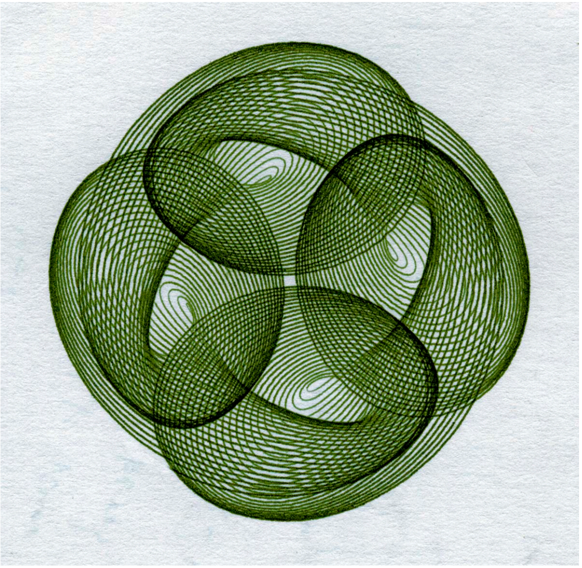


fig65

The third setting in fig65 shows the pen lift mechanism breaking the line. The synchronisation with the X axis makes secondary lines enhancing the drawing's character. The Settings are X=2, Y=3,turntable = 2. The pen lift speed is six times faster than the X axis.



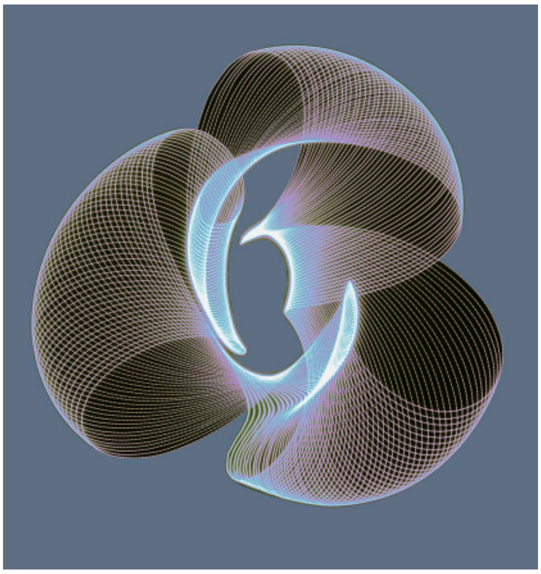


fig66 *fig67*

In fig66 a soft green pen was used and in scanning the paper texture was deliberately retained. In fig67 characteristic curve manipulation in Photoshop changed monochrome tone into colour. Ground colour was added at the same time.

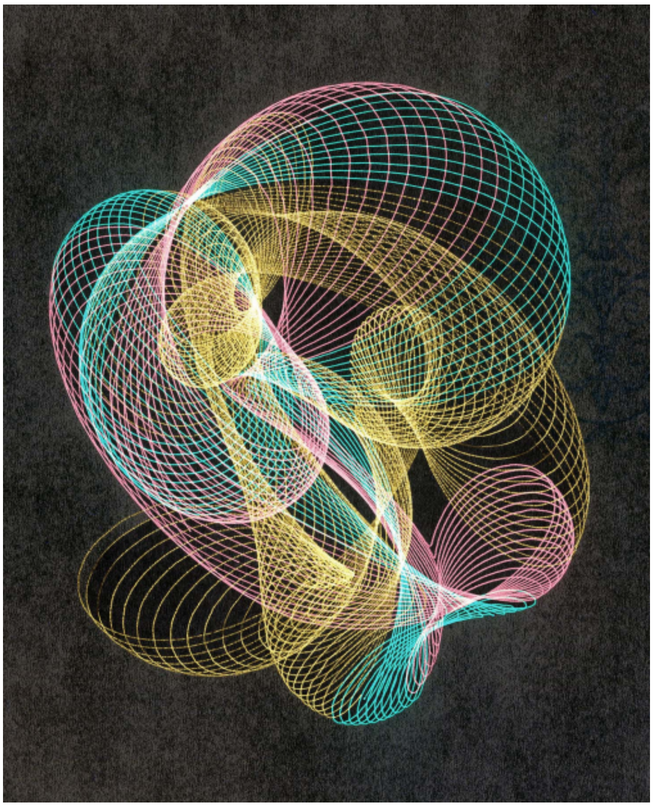


fig68

Machine accuracy in fig68 allows coloured pens to be used, without loosing line continuity. The paper texture of the original drawing was adjusted to a pale grey. In Photoshop the image was inverted tonally and chromatically. The pale grey ground, made before inversion, became a dark background texture, creating a pastel 'hand-drawing' effect.

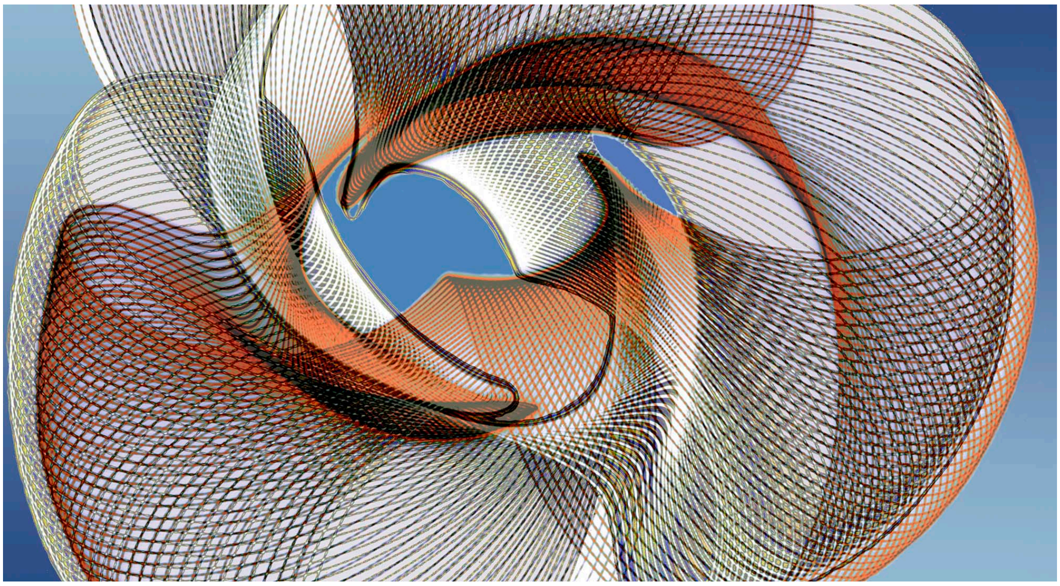


fig69

Positive and negative images, fig69 superimposed slightly off register to create a bas-relief image. As in fig67, monochrome was converted to colour and tone by curve manipulation. Background colour was added with the image close cropped to rectangular format. These actions and thinking processes are similar to those in silkscreen or lithographic printing, the computer and inkjet printer combination simply replaces the printing press.

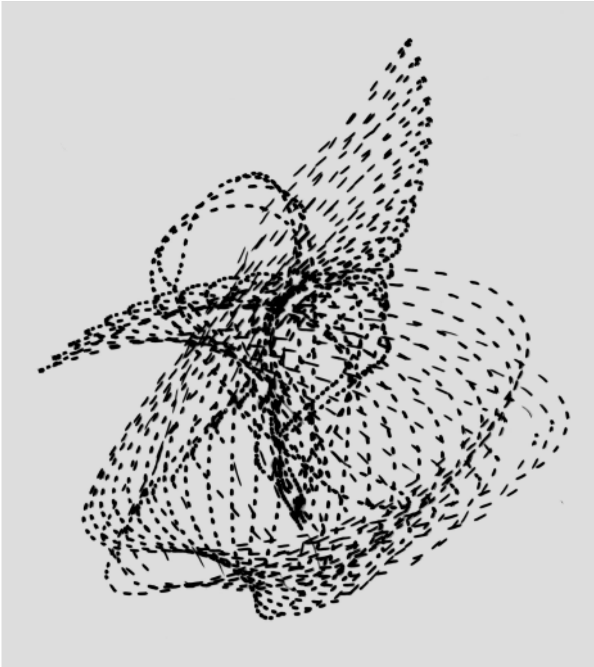


fig70

An early light trace in fig70, c 1971, was recorded on photographic paper, inverted to produce a grey ground. There was no turntable motion; the light source was subject to a shutter mechanism placed between the light source and photographic paper.

The preoccupation with line quality and elimination of backlash in gears and bearings has been a design problem from the outset. In addition the paper and pens chosen effects the final quality of output. The enlarged close up details below in figs71,72 & 73 (enlargements of figs70,64 & 66) may be compared to the normal size images. The line in fig70 shows that it falls a little short of perfect accuracy. (That in fig62 is improved due to the modifications) The trace character in fig70 is typical of a light image whilst the retention of background texture in fig73 contributes to the final effect. Similarities to classical printmaking exist in fig66 and fig68 as compared to multiple printing plates, one for each colour. The thinking process as stated above in the caption for fig69 are the same as in conventional printmaking.

fig71

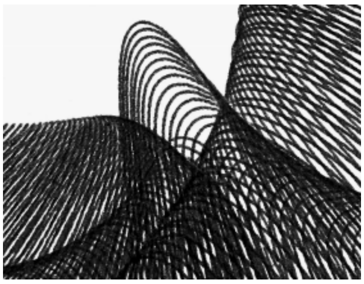


fig72

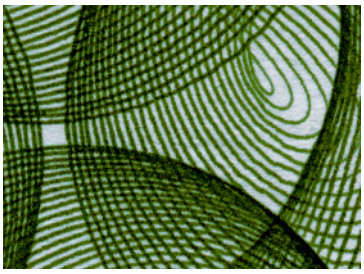


fig73

Enlargements of different line quality. At normal scale the line quality in figs 85 & fig87 is acceptable in exhibition scale prints up to 600mm wide.

Conclusion; history and applications

The Linkogram and its history of design and improvement are pivotal to my involvement in machine drawing as was mentioned in **5b.4** above. Encouraged by the success of these machines, where the images were employed in my book (Tait,1977), printmaking activities and exhibited material, it led to other machines whose purpose was to extend the variety of drawing. The images shown above represent a very small fraction of the number of drawings of which the machine is capable; the extent, as with other machines, is only limited by the time available to make the drawings and process those selected.

Early machines and computer programming

Early machines

The first machine built in the early 50's was a forerunner of the current Linkogram, a very small machine made from Meccano. It established that a cam and linkage system could easily reproduce the three principles of a pendulum harmonograph i.e. amplitude of swing, frequency of swing and, with a pendulum, the gradual running down of the motion. This running down of the swing, whilst taking the same time, always covers a smaller distance thus changing the position of the line drawn. There is also a phase change taking place between pendulums on a harmonograph as the frequency relationships of one pendulum to another are unlikely to be in exact numbers. This phase change also contributes to the shift between one line and another and causes an organic growth of the shapes drawn. What may be taken from the above is that the beauty of the harmonograph images stems from the closeness of one line to another. Controlling this line to line distance, with accuracy, smoothness and regularity of between distances governs the quality. An intense preoccupation with the design and engineering aspects of these problems takes up most of the time when creating drawing machines.

5c.2 My first machine, unlike a pendulum, did not come to a stop; a deliberate phase change was incorporated to ensure a smooth and close progression between one line and another. The running down of the pendulum creates this progression naturally and with such accuracy as to set a benchmark for all other types of machine. This crucial phase change was achieved through the observation that where two identical pulleys are coupled by a belt drive an amount of creep occurs. In practice whilst the two wheels might begin their motion each at say the 12 o'clock position, they will move relative to each other, getting out of step or more correctly out of phase. It just so happened that this rate of phase change was ideal and able to produce an acceptable line progression where one line was at around one or two line widths from the previous line. Later investigation was able to put a precise number on this relationship and it was between 1:1.0025 and 1:1.005. It became possible to make gearboxes which generated this ratio and provided a very accurate alternative to 'belt slip' devices which relied on the more random creep effect referred to above.

A later stage other machines were made to draw with light, incorporate a drum and begin exploring a NSEW idea. See the illustrations below with captions. Other machines besides those shown were built but I have no photographic records of them. Much work was carried out using light with the light source being an enlarger in the darkroom. At this stage the machines were quite rudimentary compared to recent ones as sophisticated engineering facilities were not in place. In spite of this many images were produced which were used in exhibitions and in my book Beyond Photography. (Tait,1977)

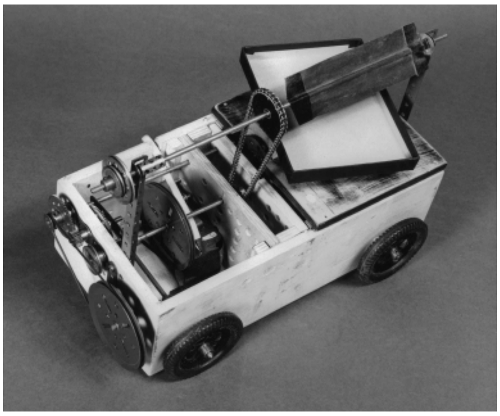


fig74

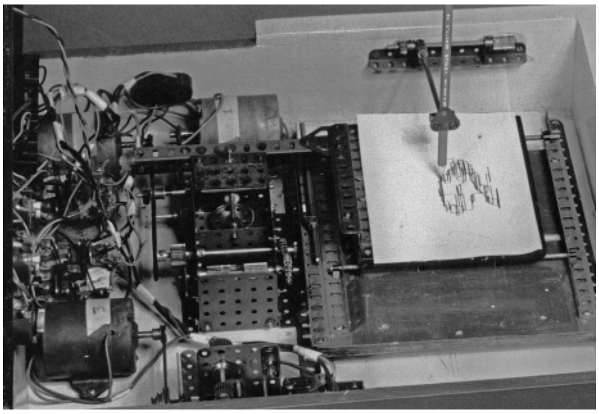


fig75

The machine in fig74 was an early machine to move colour film under an enlarger light source. In fi75 one of the first NSEW machines took an X;Y plotter form with a double reversing mechanism to increase the pseudo-random effect.

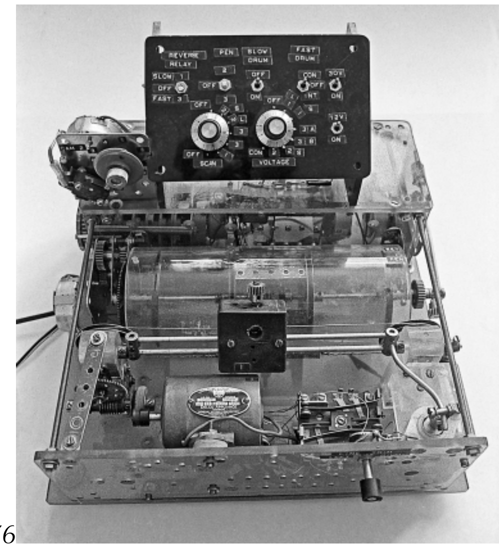


fig 76

In fig 76 the second drum machine, a hybrid Meccano/engineering mix had its own built in timer. This first drum machine was cannibalised, and was redesigned for light source use.

Programming on a Hewlett Packhard 1969 - 9125A calculator/plotter

Whilst at Newport in the 80s I was funded to pursue my PhD (not completed) at the RCA and bought a Hewlett Packhard Calculator and Plotter. This was very simple, with restricted memory, and the programmes were written in Octal language. With it I was able to write elementary programmes to explore sine waves and constructivist ideas on grids such as the Kand and KM images shown below. These were to take Kandinsky and Kenneth Martin images and write programmes to translate them into very simple images.

This activity took place, parallel with analogue machine building; at that time the only drawing machine was the Linkogram. Other machines had been made in the past but had been dismantled. The reason for this was that as they were made using a limited amount of Meccano. This was the benefit derived from switching to other methods; it became possible to keep each machine as it was developed. The plotter serving the HP computer was extremely slow and a complicated image took upwards of an hour to plot; the plotter pen moved in segments of 1 mm per second. In spite of this restriction I was able to test out ideas which were later transferred to analogue machines as the activity was expanded.

It was possible to take the formal logic of the programmes and extract from this design plans to create electromechanical devices to explore ideas such as those in my NSEW and Sinewave machines. This transfer was made easier as the HP computer was so crude and limited in scope compared to present examples. Programmes on a modern computer might have created more difficulties. Whilst Konrad Zuse in 1941, (Rojas,2010) made strides in bridging the gap between analogue and digital, my machines are very limited being unable to replicate such things as memory and nested loop logical structures. My rather crude analogue systems rely very much on the inherent characteristics of mechanical cams and linkages to contribute to the drawing's appearance.

Limited progress

The progress at this time was restricted as it occurred alongside my teaching or freelance practice. Earning a living had to take precedence; in earlier times, the images from drawing machines had appeared in books and exhibitions. Later on, when invited to mount a large exhibition at the NEC Birmingham for Focus on Imaging 2003, the drawings from the HP computer programmed work formed a major part together with images taken from early machine drawings.

Illustrated ideas

The best way to discuss the ideas from this stage is to caption each image addressing the intention of the programme. Many images presage ideas occurring much later in the analogue machines.

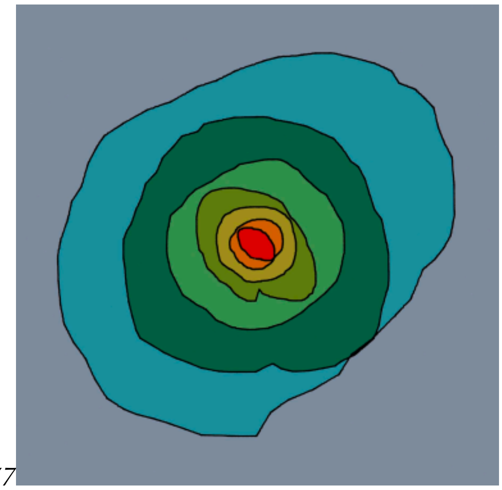


fig77

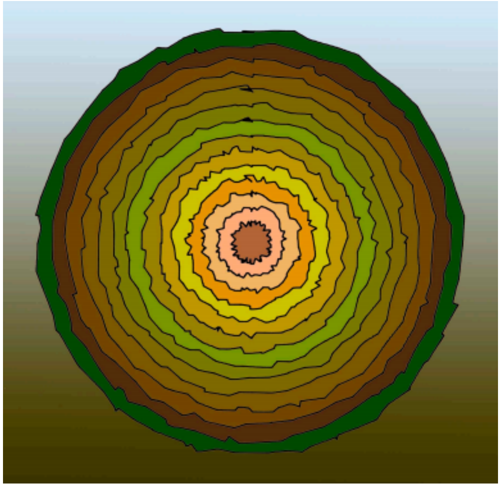


fig78

Figs77 & 78 are where the formula for plotting a circle was modified by adding a random element to give an organic feel to the circle to resemble growth. The colouring was added by hand in Photoshop.

Summary and history of early work

The early work detailed, both with analogue and computer programming, took place over a period of some years running alongside my professional teaching in art and design. It often had an influence not only on the teaching but found its way into writing, exhibitions and books. The exploratory work with both graphic drawing devices and the use of light formed a sound basis for the two intensive periods of activity.

The first machines following camera building, where engineering skills were acquired, led to precise machines which began to exhibit sculptural qualities. The second period, on retirement from freelance practice, led to an increase in the sophistication and variety of the machines. Programming assumed a growing importance. Separate initiatives began, designing independent sequential timers which could apply to a number of the machines. This continues and represents a significant conceptual advance.

Introduction to the Computer Arts Society provided valuable encouragement leading to staff at Sussex University suggesting that my professional work was written up as a doctoral study.

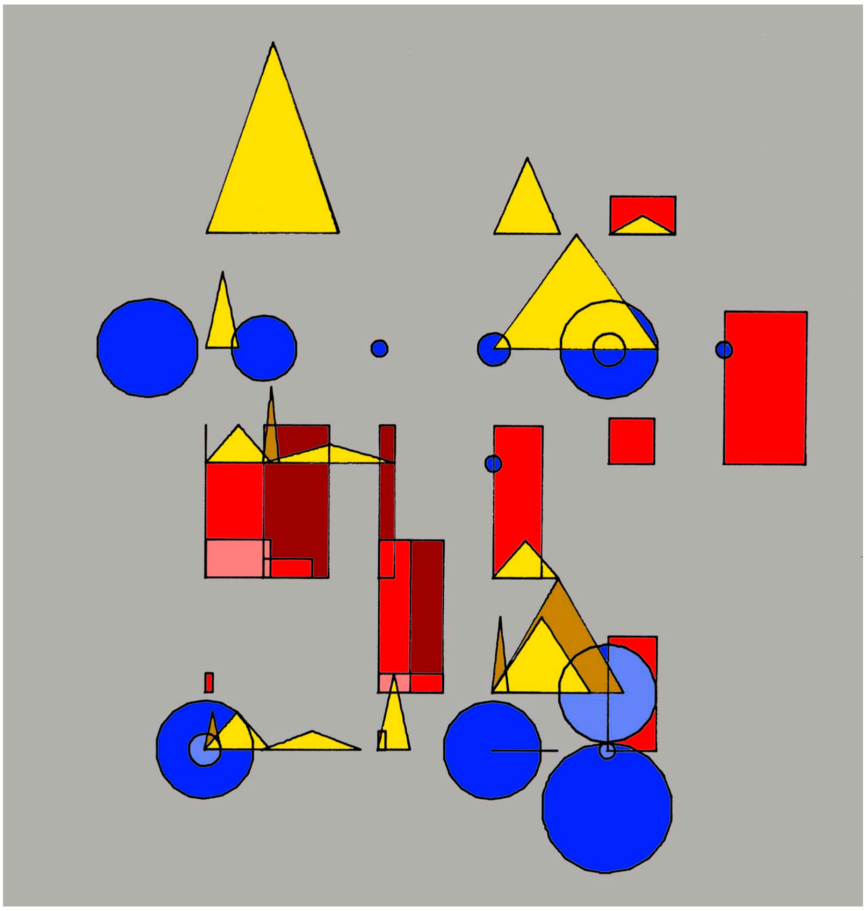


fig18

A six by six grid in fig18 'took' a random decision to choose the plotting start point. Another random choice called up a circle, rectangle or triangle subroutine. The size of the shape came next and the shape drawn. This routine was repeated 50 times. A Kandinsky inspired constructivist system led to circles coloured blue, rectangles red and triangles yellow.

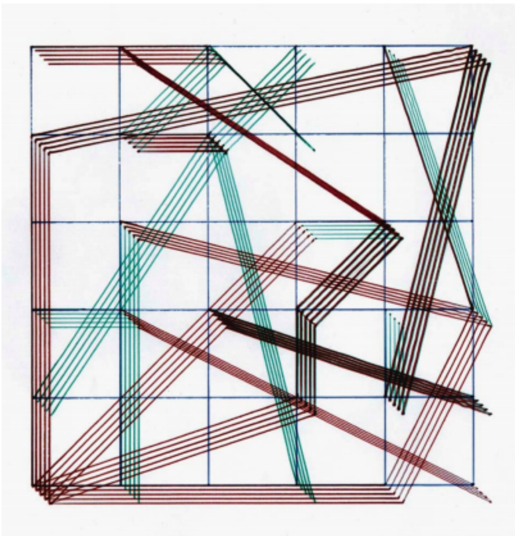


fig 16

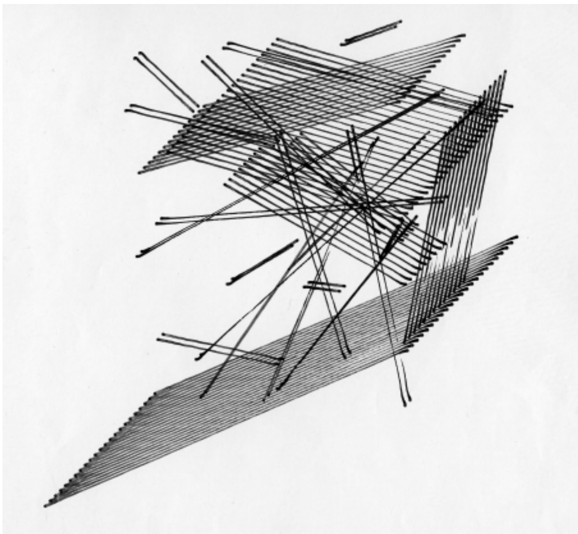
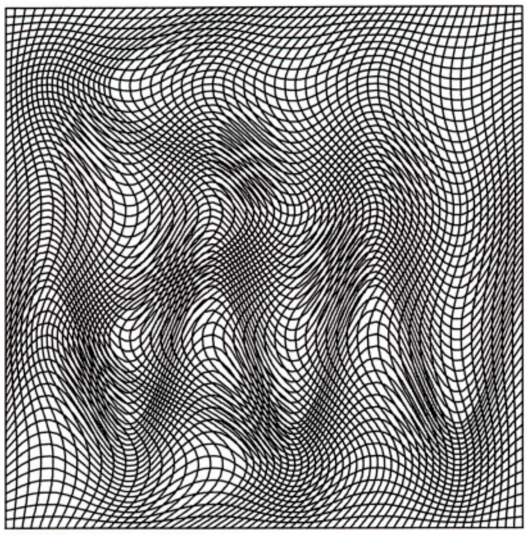


fig79

In fig16, a Kenneth Martin inspired method drew five parallel lines drawn in randomly selected locations. The routine was executed 50 times. Fig 79 was the result of a mistake in the fig16 programme but was so interesting that it was retained. 'Happy accidents' can be valuable, suggesting new points of departure.



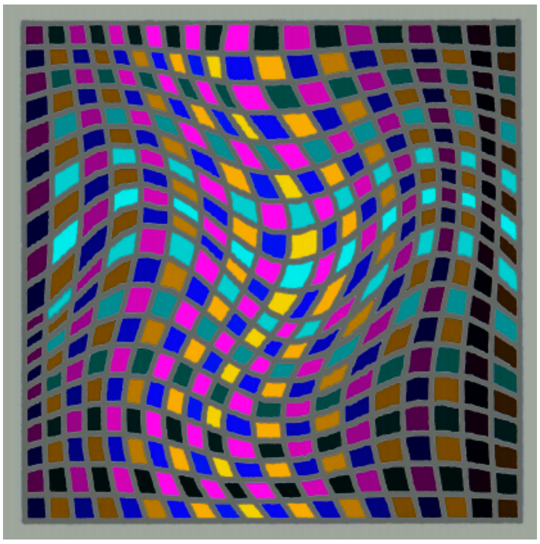


fig80 fig 81

Fig 80 was inspired by the 2:3 ratio of the musical fifth. The sine waves were programmed to grow and decay, the interval represented by the number of waves. In fig81 the colour choice was a constructivist system, using 0-255 RGB values in Photoshop. Saturated colours, blue, green, red and yellow began in the centre and incrementally lightened at the outer edge. This image is one of a pair, with colour and tone inverted in Photoshop.

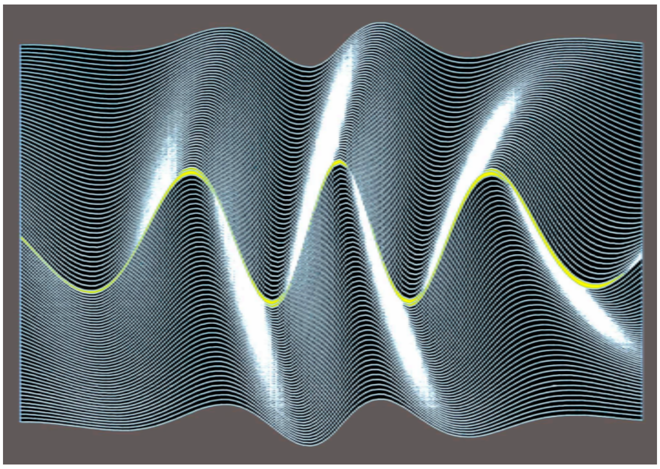


fig82 fig83

Figs 82,83 and 84are other programmes exploring sine wave growth and decay. Fig 84 led to the analogue sine wave drawing machine described below.

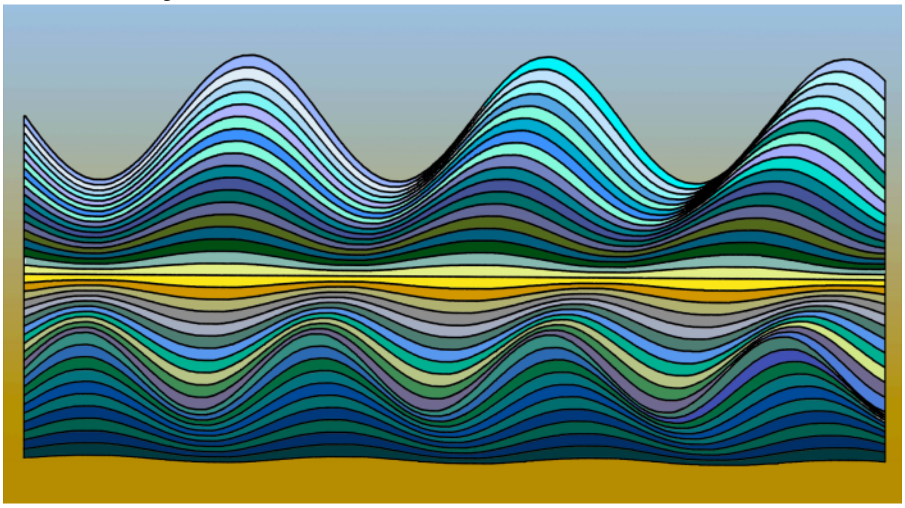


fig84

The development of recent NSEW machines made drawings which began to exhibit gesture-like qualities, representing a major step forward in conceptual terms. It was at this stage that the design of separate timers as programming devices came to prominence.

The first timer programming system had been incorporated in machines during the 70s, fig76 pg 48 It had a wide range of facilities housed in one machine. All the timer ideas in it inspired aspects of current timers. I regret that it was dismantled as its importance established the possibility of analogue programming by timer.

NSEW and NSEWsp machines

The NSEW design

These machines are unlike all the others as they rely totally on an external timer sequence. They are simple X-Y plotter designs having independent motion in an X and Y direction at right angles to each other. Each axis is driven by a separate motor in the case of the NSEW whilst the more complex NSEWsp machine has a pair of sun and planet mechanisms, one for each axis and each pair is driven by two motors making a total of four. The rationale for this is below. The idea is to give simple numeric instructions to each axis in turn, creating the potential for line movement in any of four directions at each change of instruction. The name is derived from compass points North, South, East, and West. The suffix 'sp' is added to the one to denote 'sun and planet', whilst the machine below has 'ch' to indicate its chain drive and to differentiate it from earlier machines.

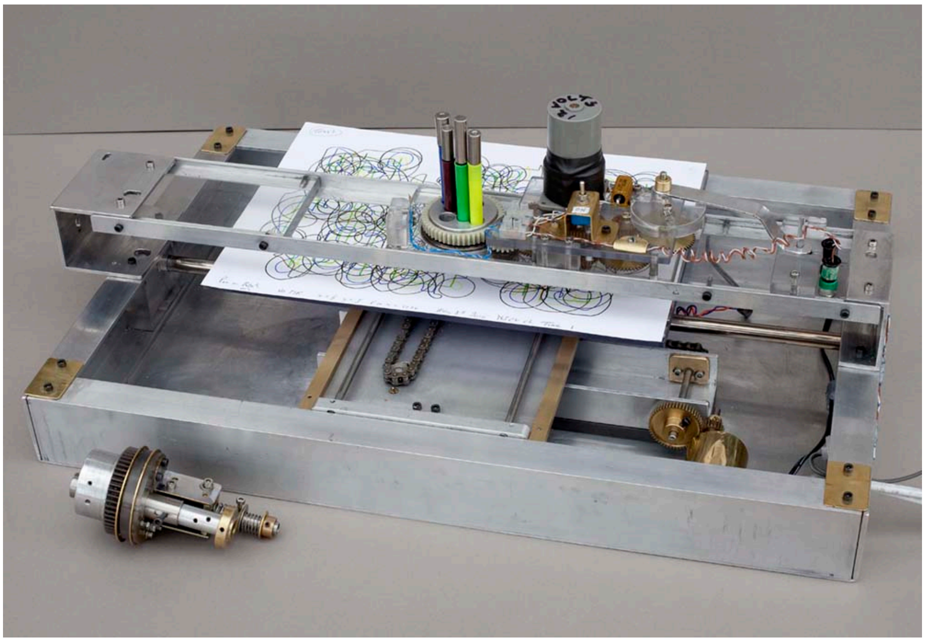


fig85

NSEWch Mk Vll machine with linear chain drive and 5 pen unit, pen lift unit on left. This machine is designed to have a similar external appearance to the Turntable and to accommodate a digital camera or light pen unit.

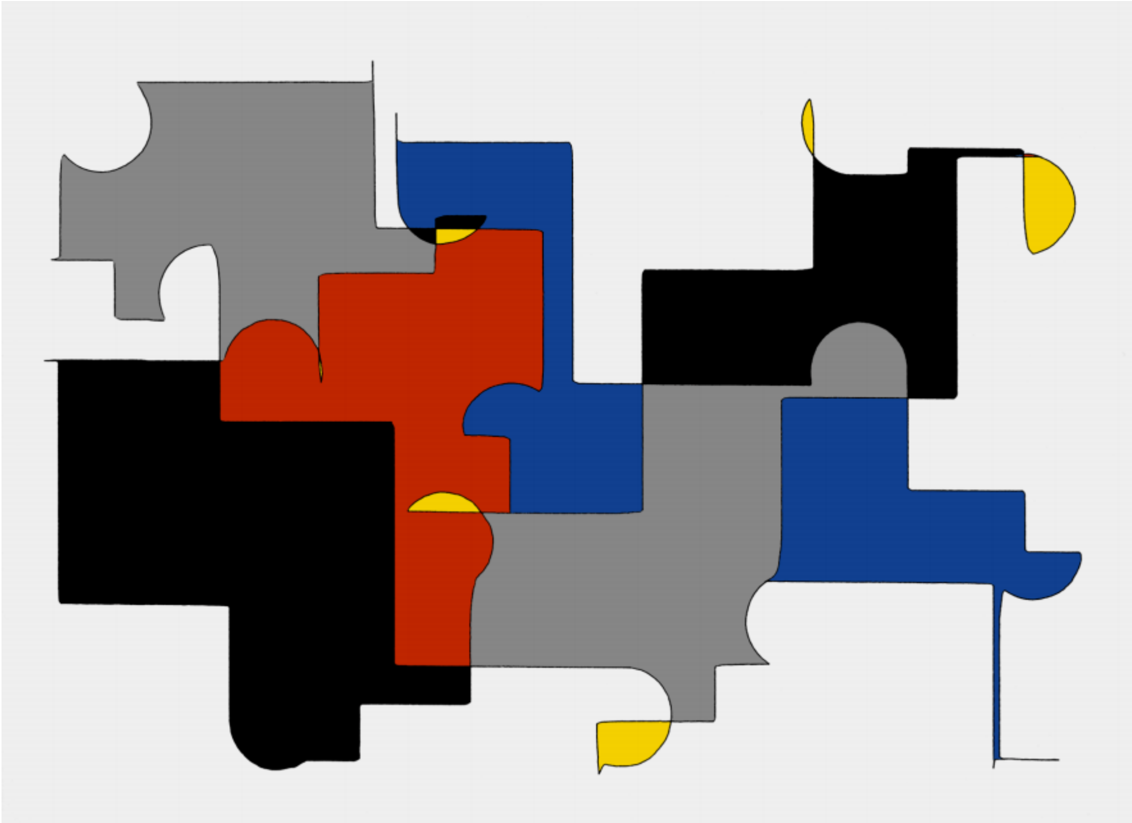


fig 86 An NSEWch drawing with '1930's' colour added in Adobe photoshop

The instructions

All the programming has one function. Timed pulses of D.C. power are issued to each motor or set of motors in sequence. They are in effect 'sequential timers'. This is a cruder version of a digital computer algorithm; instead of an 'on or off' binary code the pulses are analogue 'chunks' of time. Coupled with this is forward and reverse switching to alter the motor direction at any time. Given the independent operation of these two conditions, the line may move in any direction at any time. This is a very simple notion; even the most basic instructions can generate complexity and richness in the drawing. Having considered direction of movement the next stage is to examine its character.

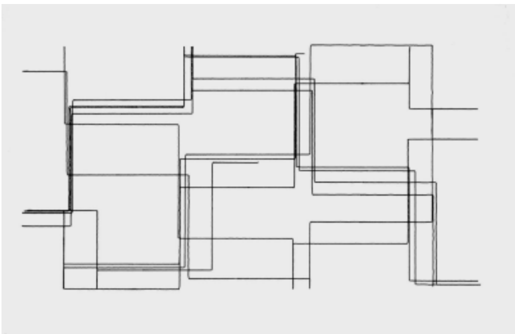


fig 87

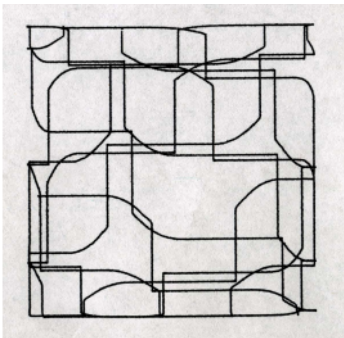


fig 88

Two versions from simple programmes. The line quality in fig 109 displays 'motor overrun' causing lines to curve, and is governed by the choice of drive train and motor.

Harmonic or linear motion

There are two ways in which a line may be drawn in either axis; the motion is either linear or harmonic. Conventional computer plotters have linear motion. The instructions of direction, speed and extent result from digital code issued to stepper motors. Linear motion can be created in analogue form; harmonic motion is an alternative choice. The advantage of linear motion is that the length of the line drawn will always relate directly to the timed output wherever it occurs in the drawing. With harmonic motion (created by reciprocating cams, which solve the direction return problem) the line length varies depending on the position of the cam. The same instruction from the programmer will generate a different line length at different stages of the cams circular travel. These two factors are the first decisions to be taken in the design of the plotter and influence the way the time instructions are converted into the final drawing.

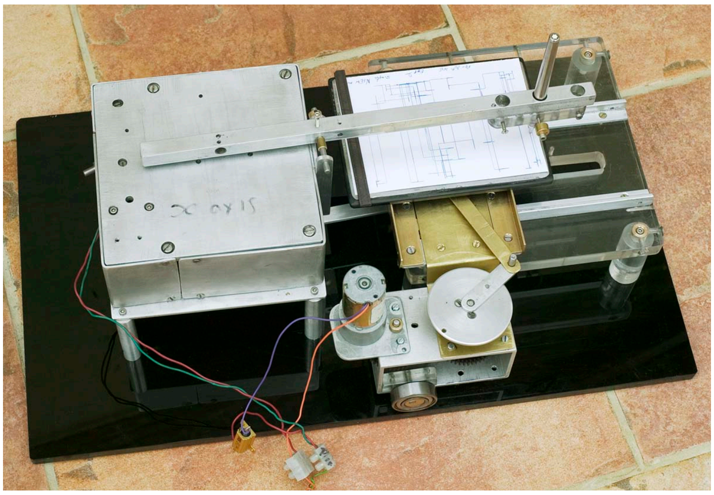


fig 89 Early Mk I NSEW , circa 2001, with harmonic motion drives

Alternative strategies in linear motion

Another method of generating linear motion is by means of a rotating drum which acts as the paper platen. This is the basis for the current **Sinewave** machine; used in an earlier versions.

Motion rationale

The choice of motion is crucial in designing a drawing machine. With analogue linear motion a mechanism must exist to stop the movement at the ends of its travel and reverse it. (This is not a problem with digital control as the programme 'knows' where the pen is and at the end of the prescribed distance stops or reverses the direction). Some form of mechanism has to reverse the direction of the motor as it reaches the end of its travel. In the Scribblogram this was done with a chain system which proved reliable but bulky. In carrying out tests for this study, an earlier NWEW machine, relying on electrical latch relays proved unreliable. It was not possible to test all the characteristics of the various timers.

This meant a redesign of the NSEW using a chain direction reversing system where a more compact chain was used. This system is shown in the NSEW Mk Vll below.

Where the drive system employs harmonic motion the direction reverse problem is simple and reliable as well as generating a different character in the drawing. As an alternative to the NSEW machine, the NSEWsp version employed harmonic motion but with the addition of a sun and planet drive on the cams to give added richness and extend the range of drawing.

To arrive at the present position of two 'X:Y plotter' configurations took many designs and redesigns before reliable machines were developed. The main development took place over a seven year period, with increased activity during the research period where the building of drawing machines took place alongside the redesign of the timer programmers so that the two would complement each other. The shift in emphasis towards the significance of programmers took place alongside a more formal analysis of the relationship between timer and machine.

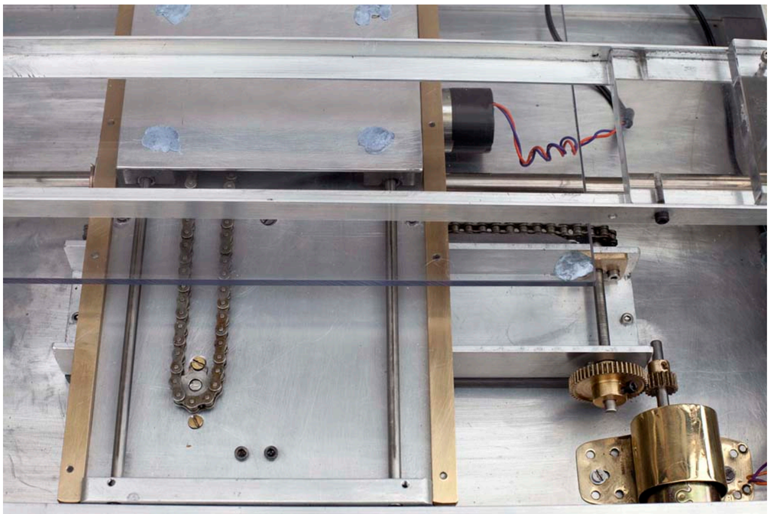


fig 90 The linear chain drive is shown, Y axis, North South on left, X axis, East West on right.

Graphic and light adaptability

Once the basic motion system (direction and character) is in place, the type of recording system may be examined. It is easier and quicker to explore a machine's potential using a graphic output as the progress of the drawing may be monitored instantly. There are a variety of pen types to choose form and in some instances where colour is needed a drawing may be repeated a number of times changing the colour on each pass. This is a sensible strategy in a programmable machine where there is a level of repeatability. In the case of a light pen the options increase at an exponential rate where the shape of the pen may be altered *(Currently the pen unit uses a large width rotating slit-image.)* As the pen rotates, the colour changes and a shutter can be used to 'chop' the lines into long, short or dot form.

fig 91, The rotating light pen unit as used on the NSEW machines

fig 92 Recent NSEWch light image with rotating slit pen, shutter and colour changer.

The problem of too many alternatives

From the above it may be held that there are too many alternatives. It is easy to propose a number of paths but difficult to rank order them. This brings the debate back to the efficacy of the criteria, the clarity of the intent and the decisiveness of the evaluation. When a light pen is used in any of the machines there are many alternatives. Whilst the clarity of intent stage is important, this should not rule out an intuitive approach derived from experience. Transparency of machine instructions is helpful in the design process. Questions arising from idea, intuition and intent lead to others concerning consciousness, psychology, philosophy and neurology, and are beyond the remit of this study. However alternative choices in decision making is addressed in Sebastian Lera's work (Lera,1980).

Pen motion extending the range for analogue devices

The main limitation with the NSEW machine are straight lines, but is offset by the circular motion of a rotating pen coupled with a pen lift facility. If this mechanism is added to the plotter configuration the range of possible drawings is increased exponentially. However this is not the most important feature. Hitherto the NSEW plotter rig has operated on a simple 'pen down' use of Cartesian co-ordinates. For example the 'X line' goes north for 3 seconds and stops, then the 'Y line' goes east for 2 and so on.

This motion may be either in graphic form or light pen. With a light pen the facility also exists to modify the pen shape and to change the colour as the drawing progresses. If a method of independently controlling the pen lift and pen actions is included in the timer output then a significant extension of the range occurs. See mechanism in fig114 below. This addition to Cartesian co-ordinates may be described as follows:-(i) Specify a destination for the pen to reach by X and Y movement. (ii) When this point is reached, bring the pen into action and perform a specified drawn shape. The drawing in fig117 below shows this.

A further extension of the range of drawings is the use of a multi-pen rotor where up to five pens may be used. This feature has been thought of for some time. During the research the problem of keeping all pens in contact with the paper and at the same pressure has been solved; achieved by means of separate weights on each pen. See fig115 below.

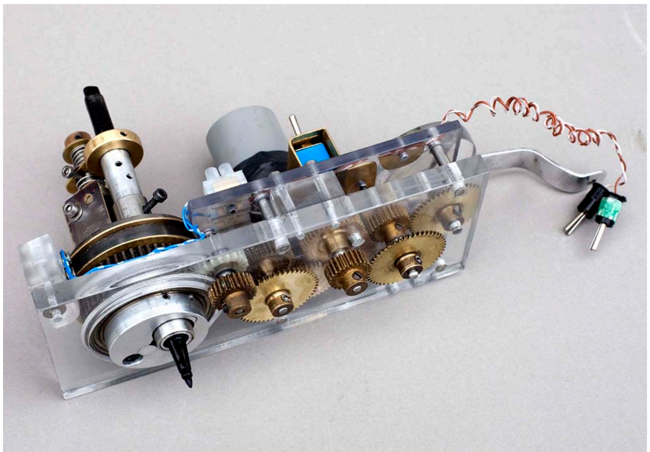


fig93 The combined pen rotator and lift unit.

fig94 Weights keep pens in contact

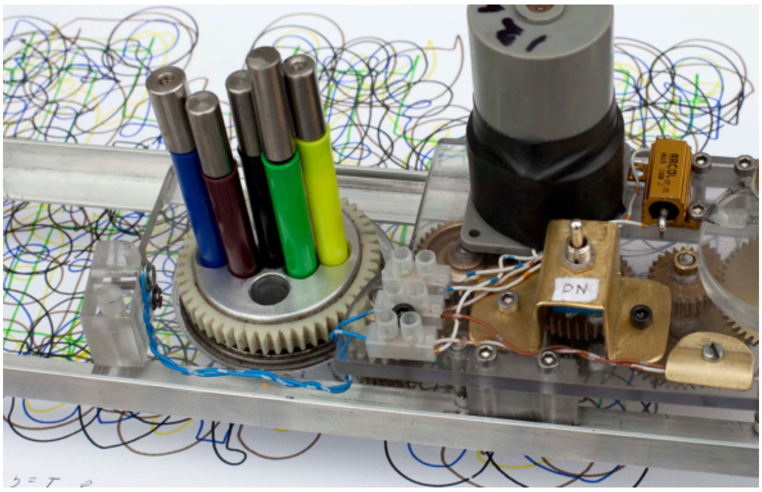


Fig 95 shows the five pens with weights on in the NSEW ch Mk Vll machine

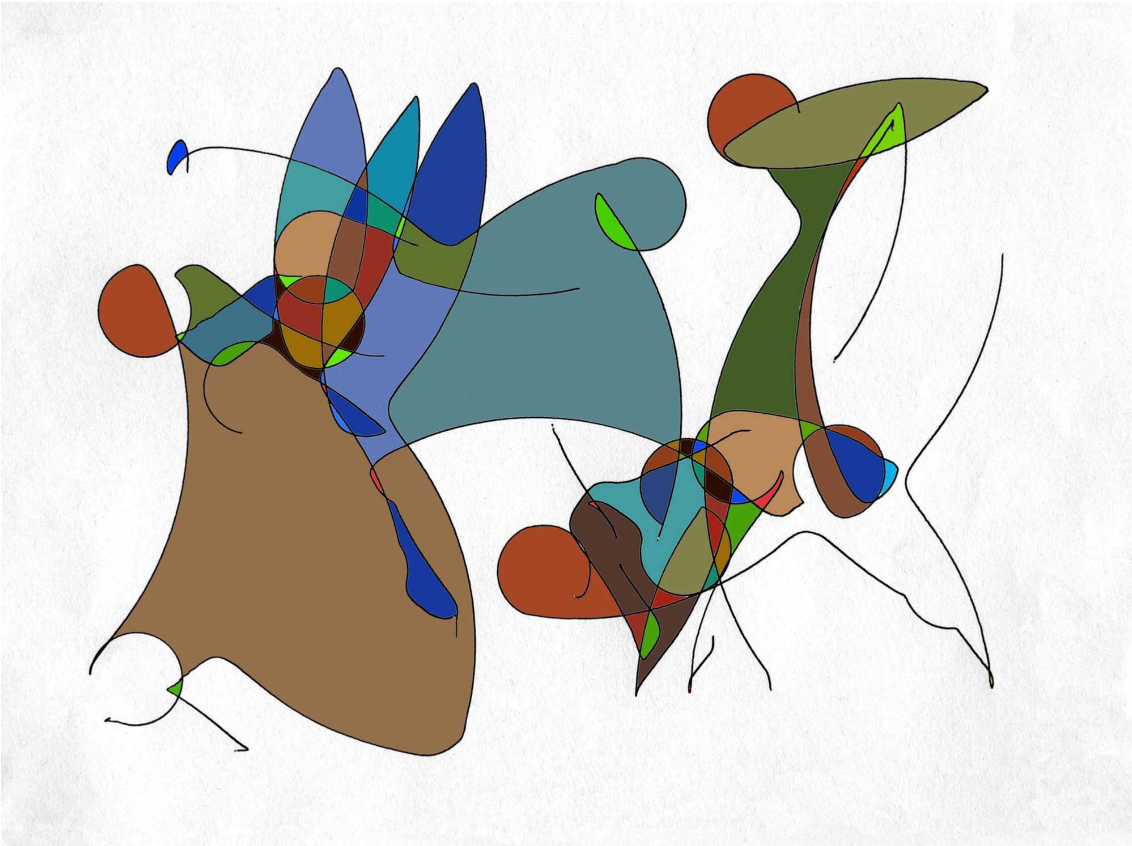


fig96 drawing using the circular pen rotation above

The conceptual advance in **fig 96** is significant in an electromechanical analogue system, extending the richness and variety of the images. Particularly when applied to more than one machine, it underpins the importance attributed to programming and increases the difference between Taitograph machines and others cited in the historical section. Another recent advance has been the completion of a five pen rotator which adds more variables to the range of drawings. See fig95 above & fig108 pg 67.

As is implied above there are many alternative paths to follow and however interesting each one may be it demands many hours of testing and recording. This part of the process forms the bulk of the work in section **4.** Here examples of all machine variables are examined and related to the combination of machine and timer which produced them.

NSEWsp machine

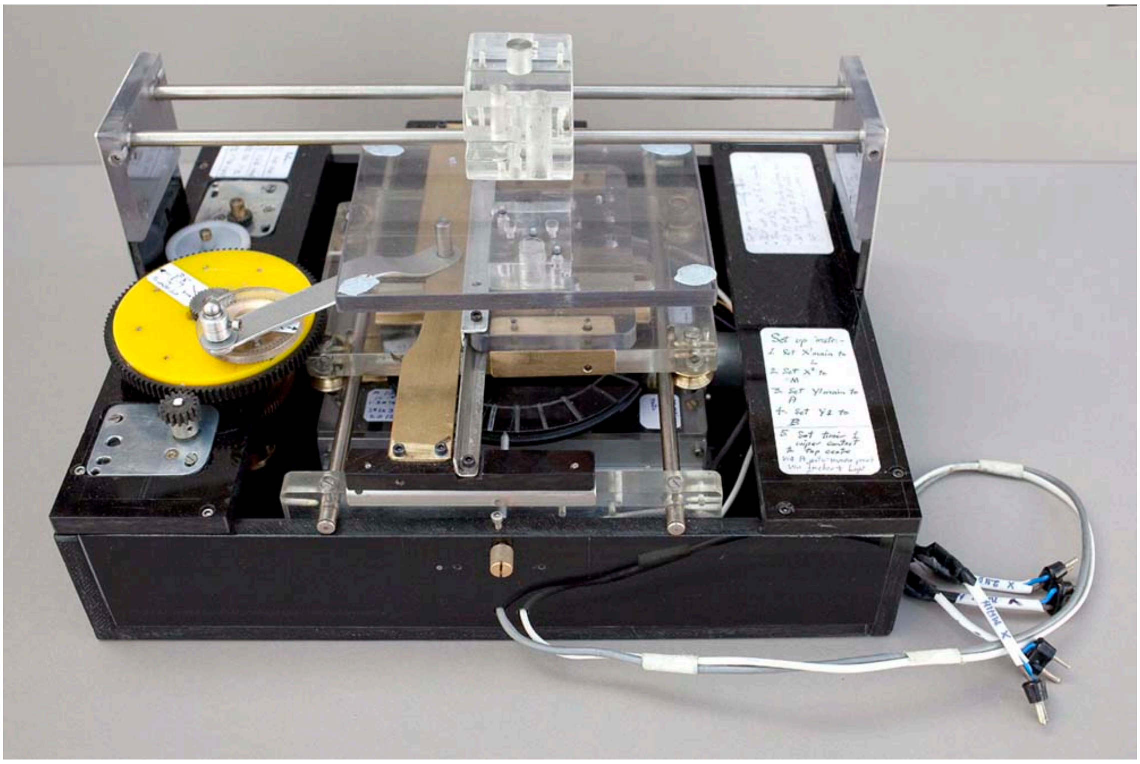


fig97 NSEWsp machine in graphic mode showing the Y axis sun and planet drive on the top right. An attempt was made here to design a unit with some aesthetic formal qualities. The same motivation applies to the NSEWch and Timer 2 MkIV. This approach is a relatively recent departure from machines which often had the appearance of laboratory test rigs.

The NSEWsp machine is set up with harmonic motion as a result of the characteristics of the sun and planet mechanism. The advantage of this mechanism is that it produces a complicated output of amplitude which varies according to the relative positions of the sun and planet gears. The amplitude variability is similar in effect to that on the Linkogram and identical to one on the Turntable machine. Amplitude variation is a crucial part of the analogue design strategy and combines with internal or external programming to offer richness and variety. Having two different motions in two machines extends available varieties; each complements the facilities offered in the other. The present array of machines aims to cover the gamut of movement in graphic or light form.

The 'sp' version grew out of earlier work with NSEW machines where a simple drive system was sought providing richness. A sun and planet gear mechanism, producing sinusoidal motion and amplitude variation, had not been tried previously. The relationship between the outer 'sun' the inner 'planet' gears permits amplitude growth to be quick or slow and is enhanced by having a separate motor to each part. Amplitude variation is sought, as in the Linkogram design, but there it was achieved differently. Each mechanism creates its own character but the methods are interchangeable. The Linkogram could just as well have been built using a sun and planet mechanism instead of the in and out of phase twin cam system.

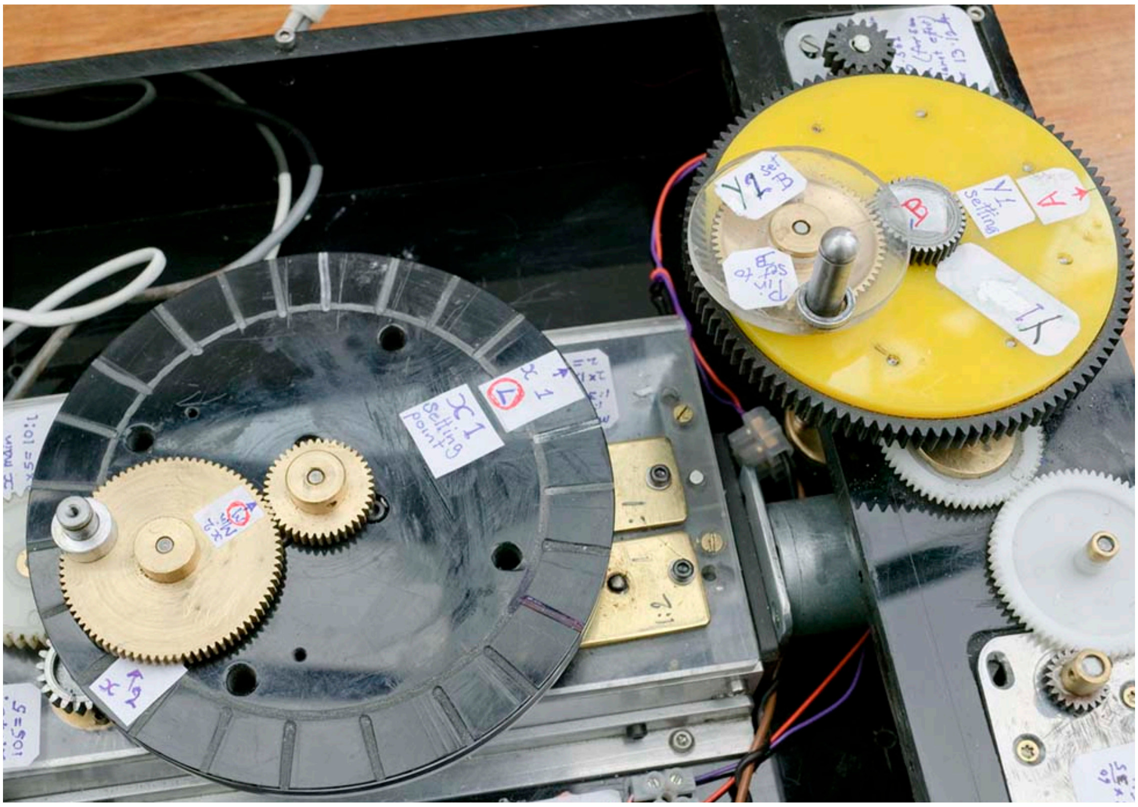
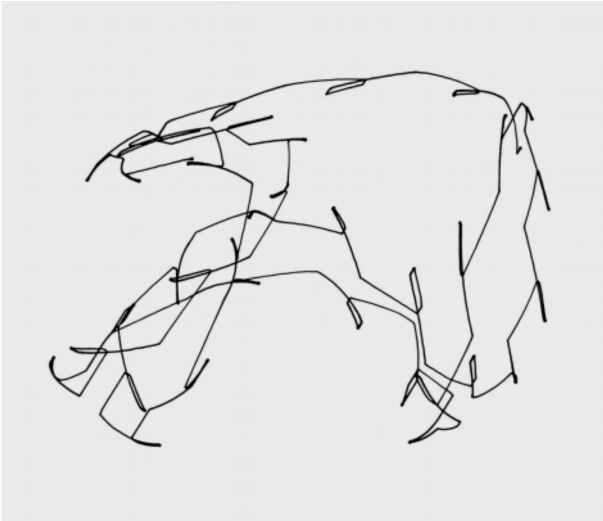


fig98 Two sets of sun and planet gears - NSEWsp

Alfred Hoehn (Hoehn,2008) has used a sun and planet mechanism in his drawing machine currently showing on You Tube. His machine does not appear to be programmable and it is uncertain, from the data offered, whether it is capable of such a wide variety of drawings as a Harmonograph. Repeated attempts to contact Hoehn via his website to obtain further detail have been unsuccessful.

As in the case of the NSEW machine the 'sp' version is dependent on an external timer for its programme. However the two motor drive system results in a large increase in the number of drawings possible. If my maths is correct, the total of different drawings from the NSEWsp and the timer is approximately 37,000,000. A theoretical number but in practice it can be argued that the range provides scope for a number of creative strategies.



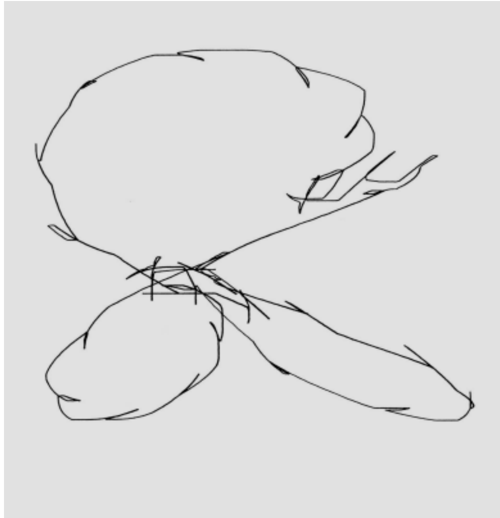


fig99

fig100

Figs99 &100 show a 'gesture-like' line quality from the NSEWsp machine

It was found, by accident, at the early stages of programming, that a particular way of ordering the instructions was rewarding. It was assumed that timer outlet 1 should be connected with the two X motors and the two Y motors connected to outlet 2. By mistake the leads were put into the wrong outlets from the timer and causing the sun of the X axis to be coupled to the planet of the Y axis and vice versa. The richness of drawing that this produced represented a major step forward. It began to produce a gesture-like quality of line which had been absent from previous images.

I realised that this arrangement prevented the machine from drawing a straight line owing to the combination of an X:Y input from each instruction. Furthermore X combined with Y did not produce a straight diagonal as would be the case with a conventional X-Y plotter. In Cartesian terms X and Y together generate a diagonal line.

The chance occurrence above resulted in each simple instruction producing a complex mathematical curve. The shape varied relative to speeds of the sun and planet gears and depended of the relative positions of the sun and planet when the instruction was given. The outcome was that the simplest instruction e.g. run two motors for 3 seconds, then run two others for 4 created a very complex curve. Line character is enhanced by a forward and reverse element in the timer. This was the original intent. When a gesture-like line could be created with such simplicity, it encouraged speculation about the similarity between a hand drawn line and that of a machine; with all the philosophical overtones this implies. In art and design process, exploiting a chance event is a helpful strategy.

NSEW drawings

The drawings below, together with those already shown, are chosen to give some idea of image variety available from the NSEW and NSEWsp machines. The NSEWsp machine is difficult to reset to repeat a drawing with any accuracy owing to the complex nature of the sun and planet drives. An interesting parallel exists (reference to Chaos Theory, **2**); that accurate setting of a start point is very difficult. The start point chosen has a crucial influence on accurate repeatability and the character of the drawing. However with some care it proved possible to do two drawings in different colours on the same paper. The level of conformity achieved is evidence that, even with the most challenging machines, it is possible to uphold the claim that they can function as design tools. Fig 122 is accordingly a very significant image.

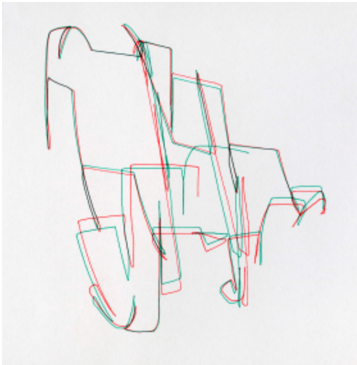


fig101 NSEWsp *repeatability 'proof' drawing, two images, same programme in near register*

fig102, NSEWsp drawing from the chance event with gesture-like line

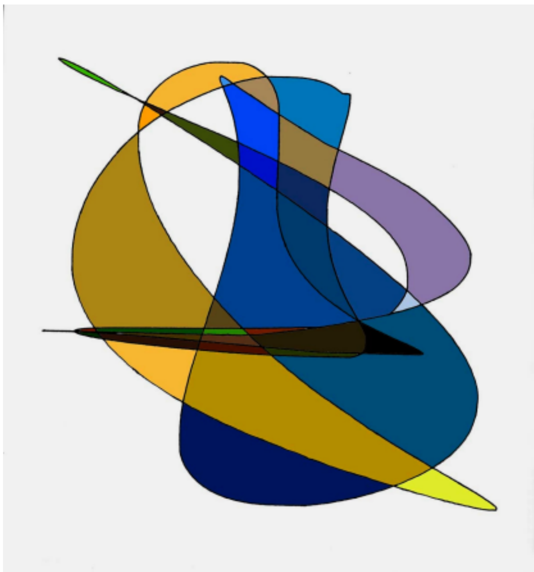


fig103

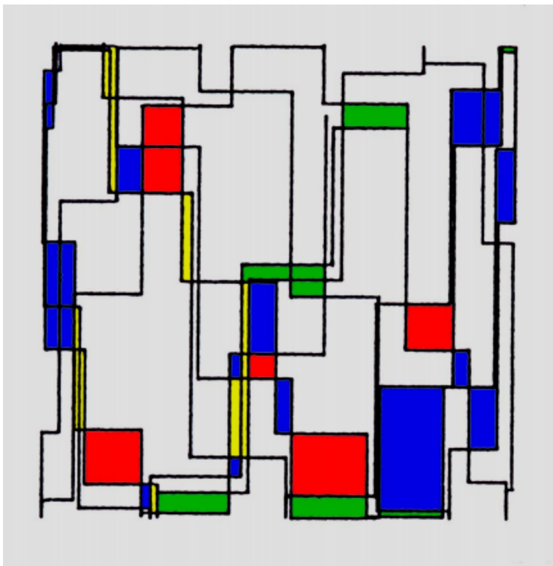


fig104

Fig103, NSEWsp drawing with one axis only, fig104 NSEW drawing from simple programme

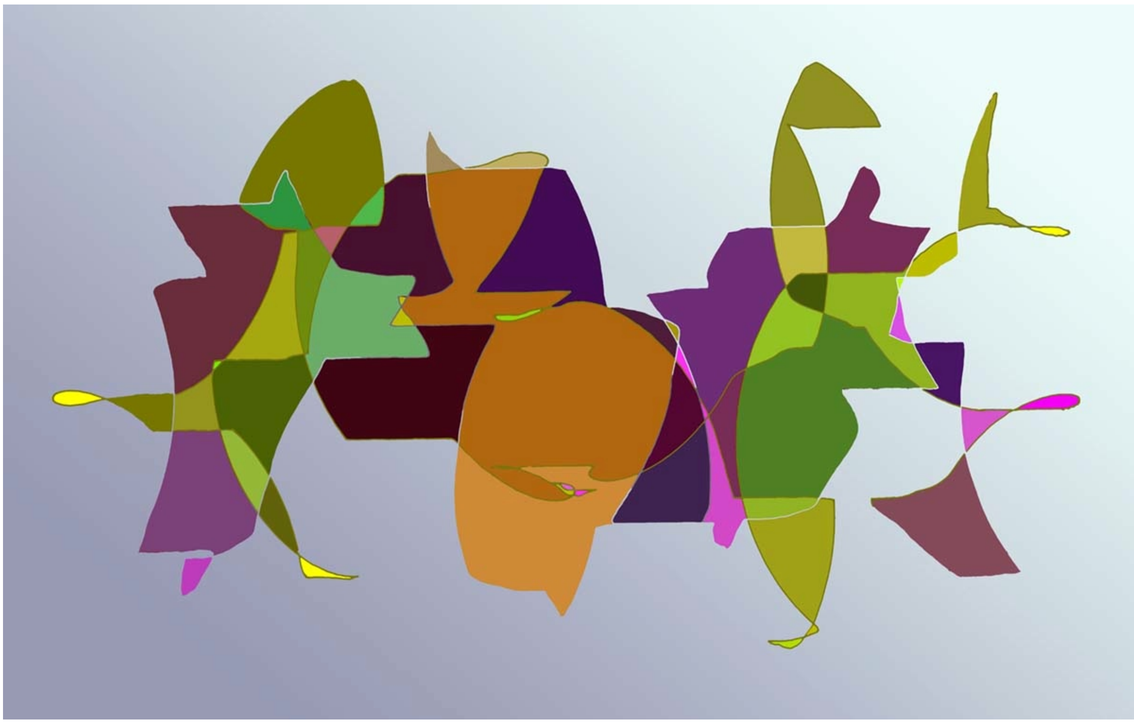


fig105

Fig105, NSEW with rotating pen fitted but no pen lift

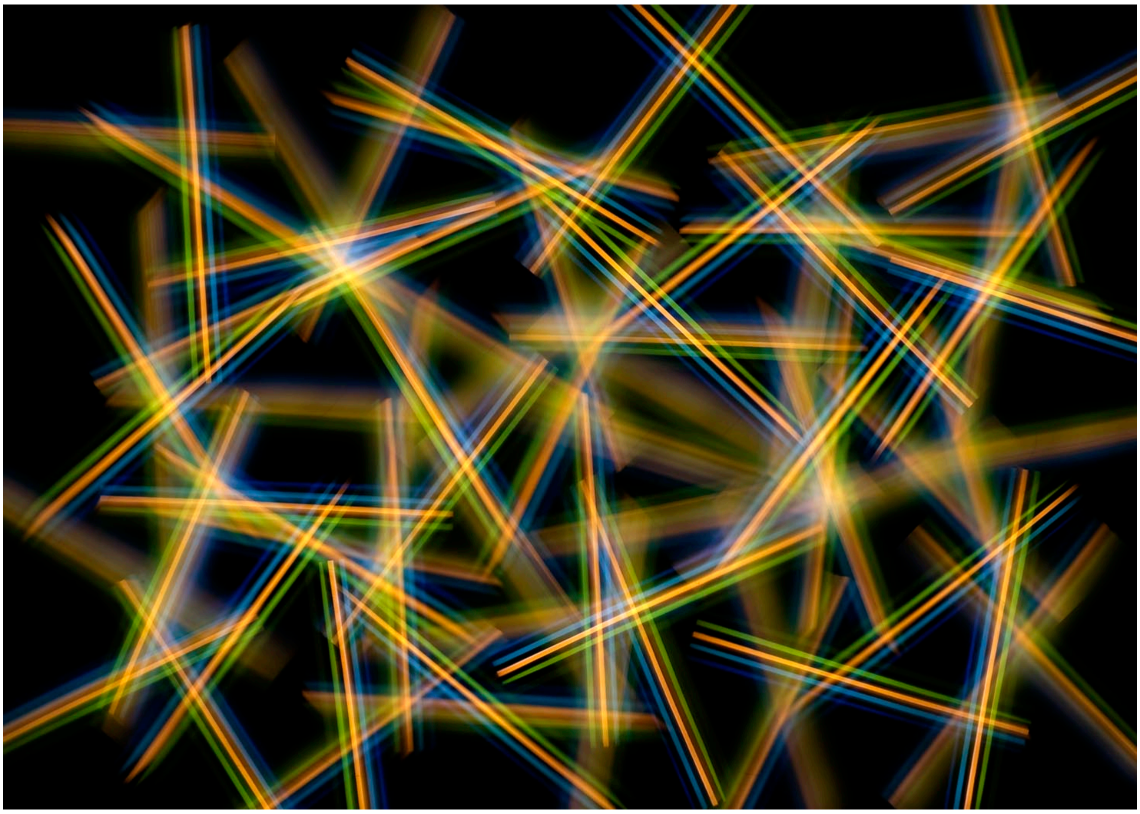
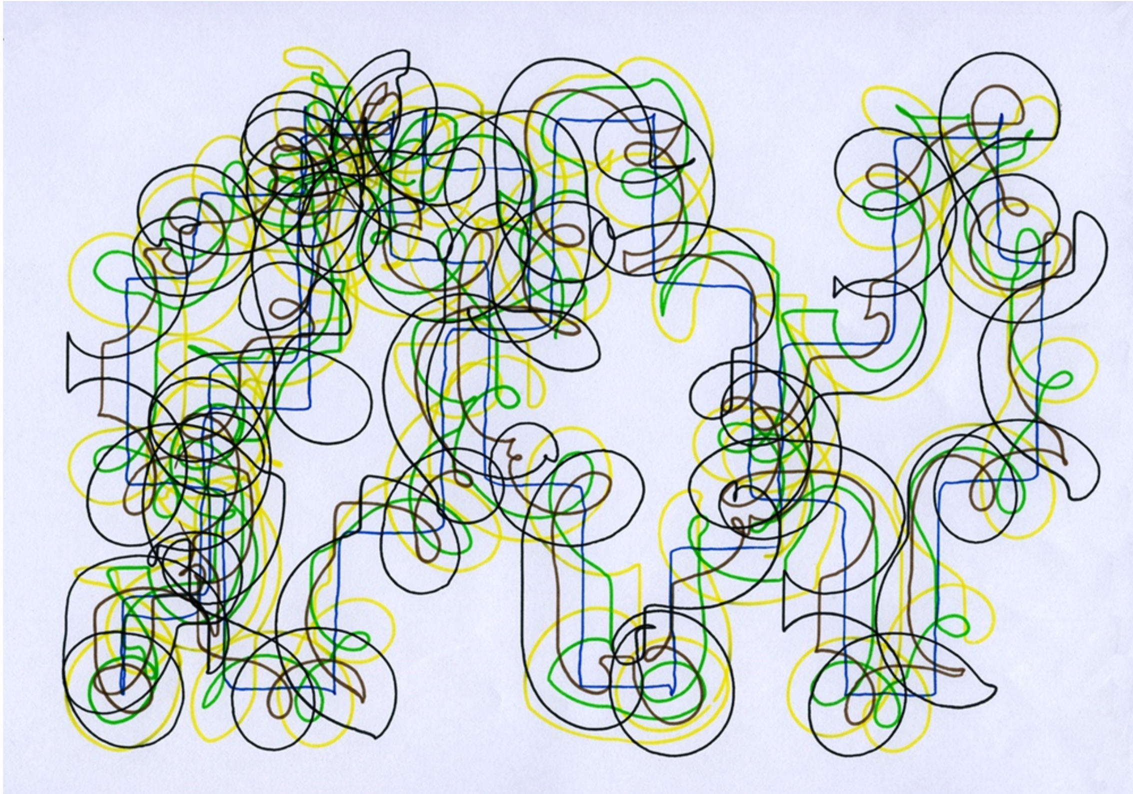


Fig106, light drawing, rotating-slit light pen, shutter, fixed colour wedge with Timer 2

Fig107, a light drawing from the NSEWch machine onto digital camera; with Timer 4

Fig108, NSEWch (Mk Vll) machine image using the 5 pen rotary unit with Timer 1



Summary

By choosing to build NSEW and NSEWsp machines based on linear and harmonic movement respectively, the range of available images is extended, particularly in the case of the NSEW machine where rotating pens either in graphic form or light can be used.

NSEW rectangular drawings complement the Turntable circular ones. With other machines; Linkogram, Meccanograph and Sinewave, they explore range of varied kinetic action. Each is designed to further a drawing action and explore how simple instructions generate complexity. The Scribblogram exploits cross-hatching as a graphic means of suggesting tonality. From the innovations, pen rotation and lift, light colour changing units, and multiple pens, have contributed more to the expressive range than anything else. These, coupled with programme transparency, might offer some insights into the mix of engineering, design, and photographic skills as contributory factors in art and design process.

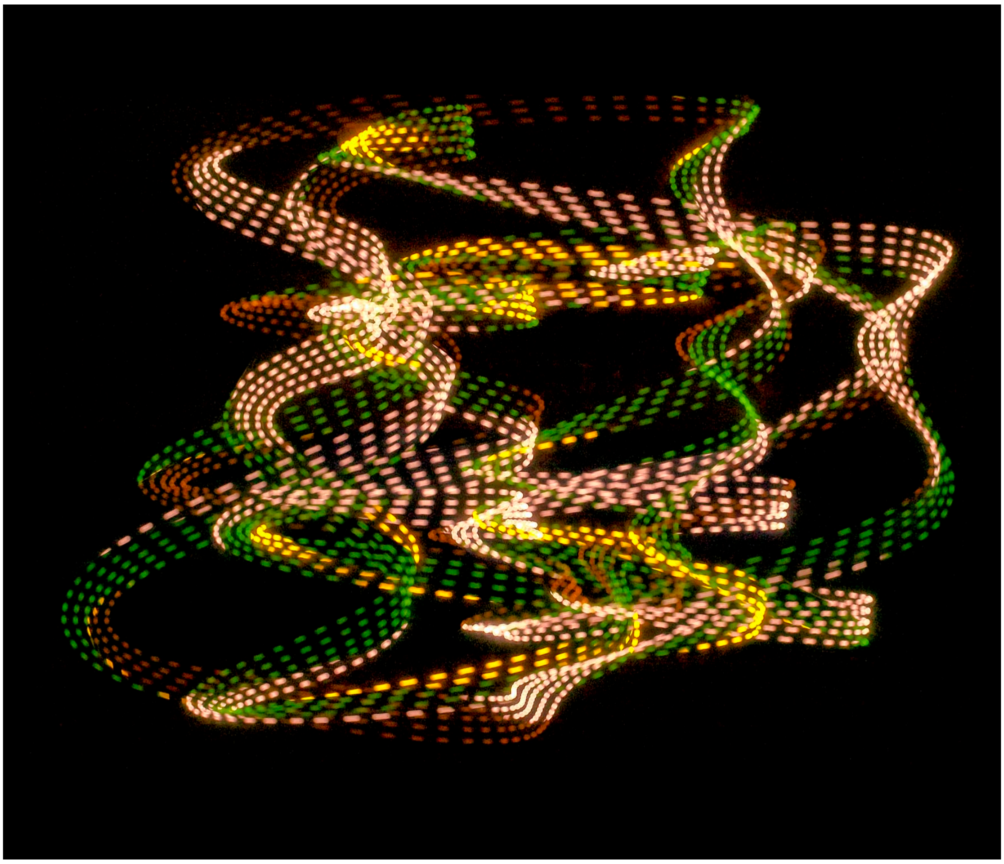


Fig109, a five point light source was used here together with a shutter

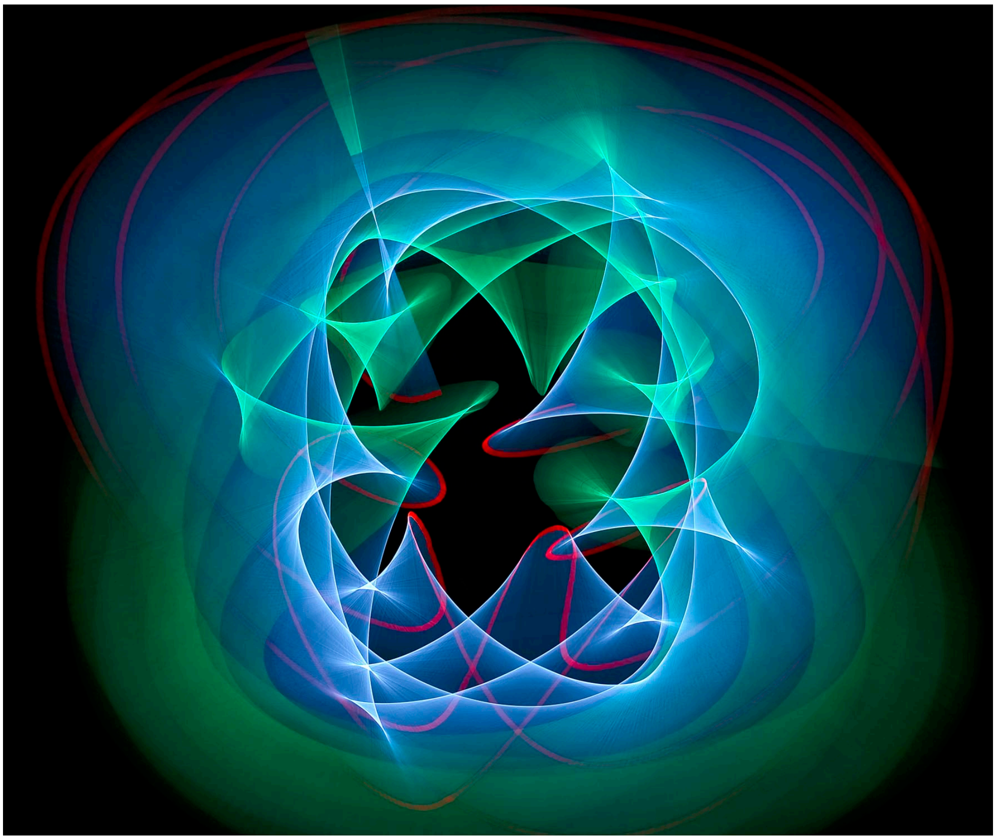


Fig 110, light drawings made with the NSEWch machine and camera rig including a colour changer, and variable light size. These two drawings represent the latest development encouraged by the exhibition preparation and are a significant step forward

Sinewave machine ('Sinewave' is the designated name for my machine)

Digital to analogue; design problems

Following work done on sine waves with computer programming, I was interested in the challenge to make an analogue machine to explore my pre-occupations further. The problem solving is described in detail as an example of design process, where a number of interdependent actions must be co-ordinated with great precision. This is the case with all the machines, but was particularly complicated here. The outline of the solutions adopted should illustrate the design process. The problems are listed below:-

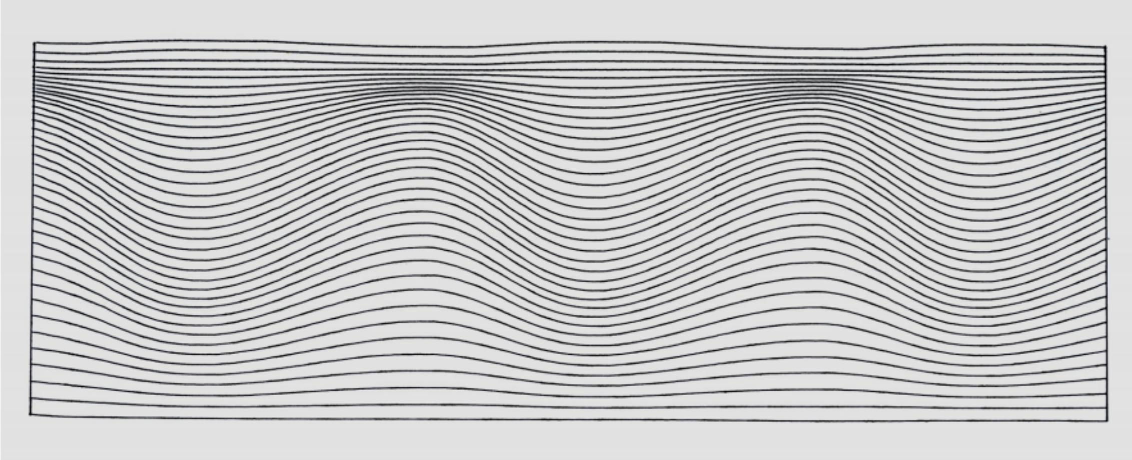
1. Drawing the basic sine wave, returning the pen to the exact position on the sine wave cycle after one line is drawn.
2. Making the waveform grow, zero to maximum, and then reversing this growth.
3. Moving the next sine wave line exactly at the same position with a controlled degree of line progression.
4. Creating a wave break action to occur at the crest of the wave; this was the most problematic.

To achieve all these goals there are four mechanisms to be brought together.
These are:-
***a.** The sine wave creating unit together with the wave amplitude control, a combination of 1 & 2 above.*
***b.** The double-decker sine wave carriage and the pen carriage, achieves the task in 3 above.*
***c.** The drum drive unit incorporating a drive from the sine wave unit as well as differential gearbox.*
***d.** The wave break and pen lift units. The pen must lift clear of the magnetic paper holder at each revolution, operating the micro-switches which 'tell' the line advance and wave growth units how fast to go.*

All mechanisms are subject to the control panel which acts as the 'programmer' so that a large number of different drawings is available. This machine is very complicated, but it does demonstrates a relationship between:-

INTENT *make a sine wave image,*
PRODUCTION METHOD *design problem solving and precision engineering,*
CONTINUOUS EVALUATION *of line quality & spacing, wave characteristics, controlled programming needs and repeatability.*
Fig111, simple sine wave; wave growth minimum to maximum, reverting to near minimum.

5e.2 The design solution



The first task to create a sine wave is easy; any rotary motion is sinusoidal (creates harmonic motion). A cam and linkage makes a reciprocating motion. A simple sine wave was not sufficient. An exact number of waves was required, beginning and ending at the same place in the cycle. Not only had they to be repeated when the next line was drawn but placed at specified line to line distance. A number of solutions were examined involving a reciprocating carriage for the paper. Each raised the problem of carriage return to starting position at the same place in the sine wave cycle.

Many solutions were rejected as they involved too much mechanical complexity. Simple answers are best; often elegant and precise. The design process frequently goes from the complex to the simple. The solution which met the requirements was a rotating drum (see fig 141 p92) acting as the paper holder and with the pen mechanism **P**, fig 134, set to draw the wave forms onto it. After one complete rotation the pen returns to the same starting point and the sine wave is uninterrupted.

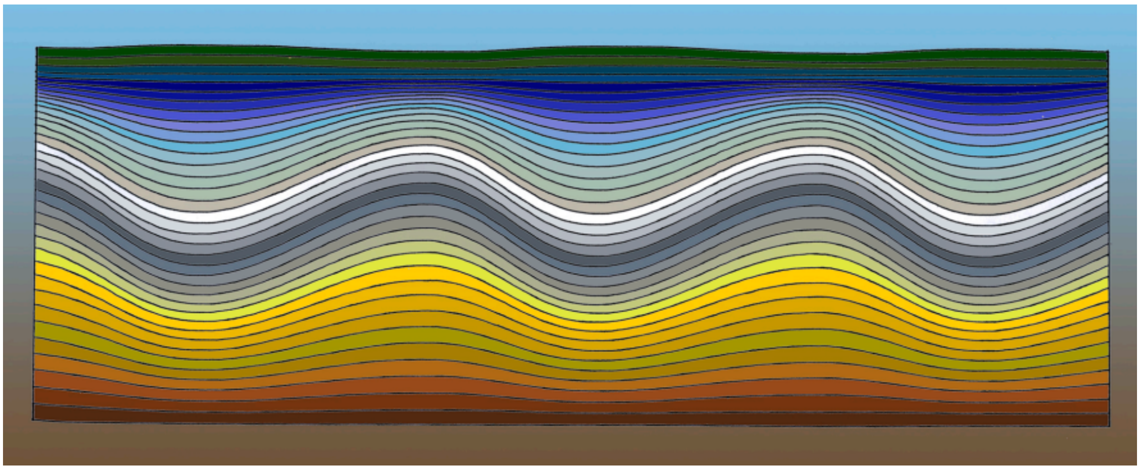


Fig112, a finished picture processed in photoshop from a fairly simple drawing.

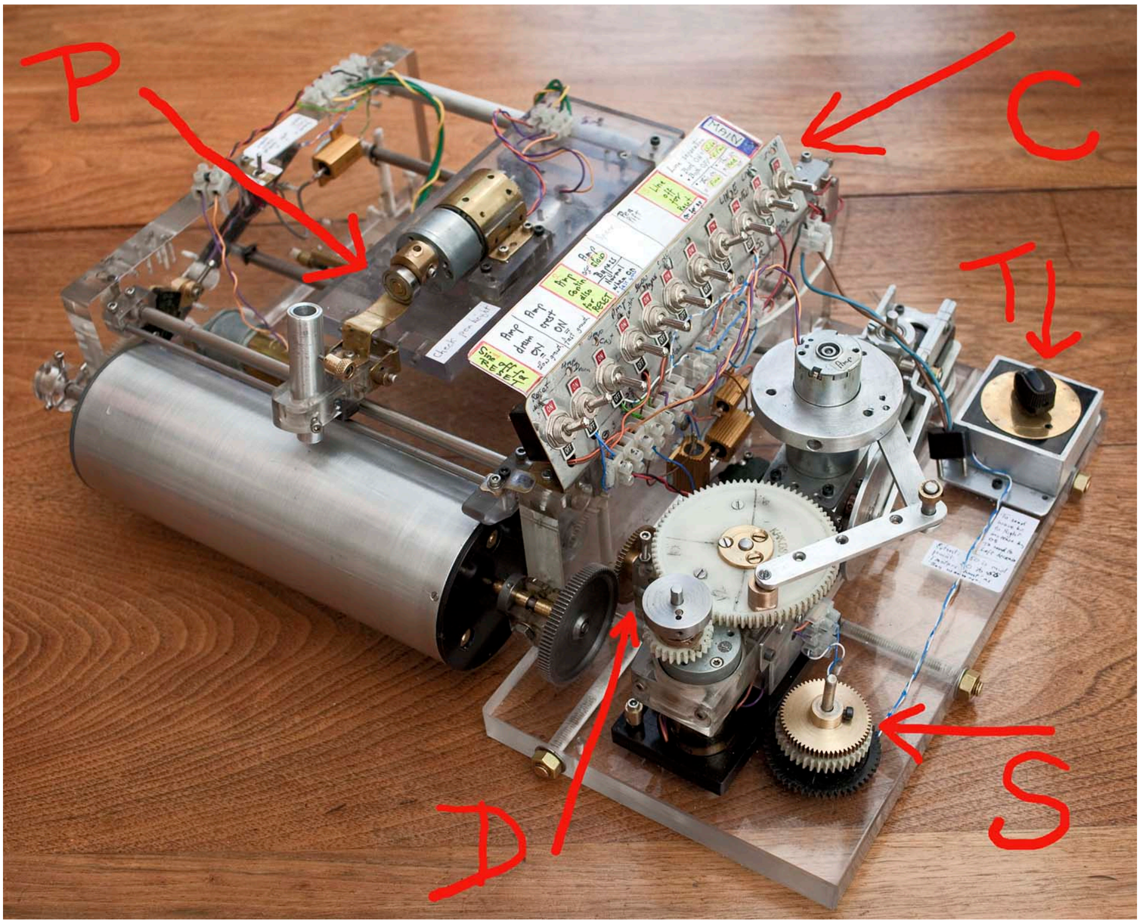


Fig113, Sine wave machine, reference photograph showing the drum as a platen.
KEY:- *P=pen lift, C=control panel, T=trim pot., D= main drum drive, and S=other drive gears*

Wave motion and line advance, the double-decker unit

Having solved the main problem regarding the uninterrupted sine wave cycle the remaining actions to be added were the line progression or advance, preferably close to one line width distance, and then the line amplitude growth and decay mechanism. To avoid complexity these two actions were combined in one unit, a sort of double-decker arrangement. This meant making a sine wave carriage, the lower deck, to transmit the sine wave motion which was coupled with a linkage to the main cam wheel. On the upper deck the pen carriage is seen in place in fig134 above labelled **P.** The pen carriage rides on the back of the sine wave carriage and is advanced by the line advance motor which engages a rack and pinion drive train. This group of mechanisms form the heart of the Sine wave machine and are examined in detail below.

In the pictures below, all four relate to the double-decker arrangement described above. Fig135 shows the sine carriage which runs on the middle rod **R** near the brass rack. This unit is coupled with the linkage **L** to the ball race bearing in fig135 which is attached to the lower deck. This is made from a large piece of Perspex and its weight is balanced on the bearer rod **R** by the weight of the upper deck pressure of the brass rack. This means that only one simple heavy duty rod was needed as a guide which is easier than two rods, which call for more precision and can create drag. This simple solution contributes to the smooth running of the carriage. The pen carriage, shown upside down in fig136 gives an idea of this weight as it carries the line advance motor **LAM** and because of its mass has to run on heavy duty ball race bearings (see **BR** in fig136) which run along 8 mm stainless steel bearing rods placed either side of the lower carriage. Fig137 shows the gear drive to the line advance pinion as well as the side ball race bearings which prevent any lateral shift of the heavy pen carriage as it moves smoothly along the bearing rods. Finally in fig138 the pinion on the underside of the pen carriage is shown meshing with the brass rack. The weight of the pen carriage, mentioned above, not only balances out the lower deck, keeping it level but also ensures that the pinion and rack are in perfect contact. Any possibility of backlash would be damaging to the precision of the line. The two decks move to and fro together in accurate register.

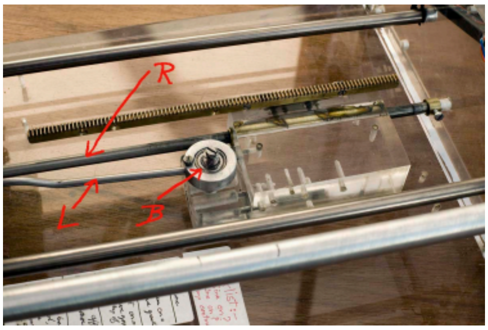


fig114

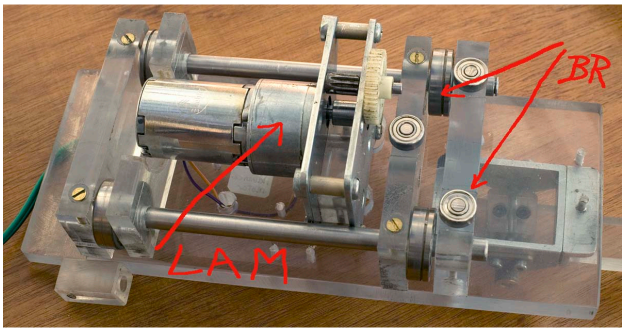


fig115

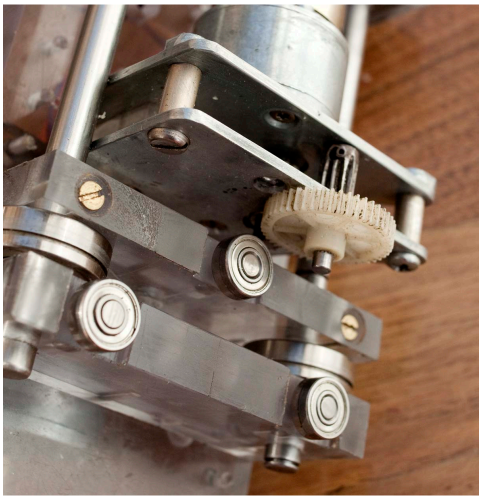


fig116

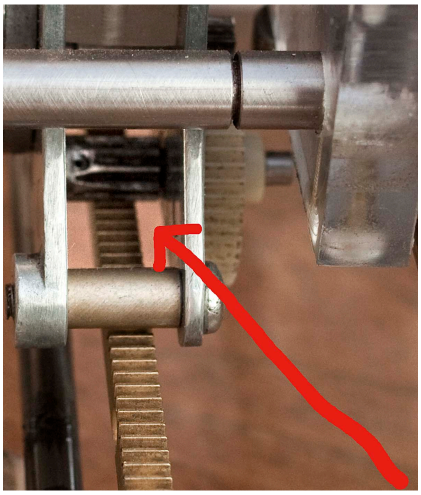


fig117

The whole character of the machine depends entirely on the precision of every component when many interdependent mechanisms are in play. This is a chain; any weak link would not allow the original idea to be realised.

Wave growth, sine wave creation and amplitude

Having established the double-decker set up where two actions are combined into one mechanism, the description can move to the next pair of interdependent units, the wave amplitude control and the wave generation device. The easy part is the generation of a sine wave using a rotating cam and linkage in fig135 above. The difficult part is to make the wave grow and decay from zero to maximum. Each action is described separately and the combination shown.

The sine wave motion is made with the wheel **C,** fig139 connected by a linkage to a slider carriage which pushes the double-decker unit to and fro. This can be seen in the two pictures below.

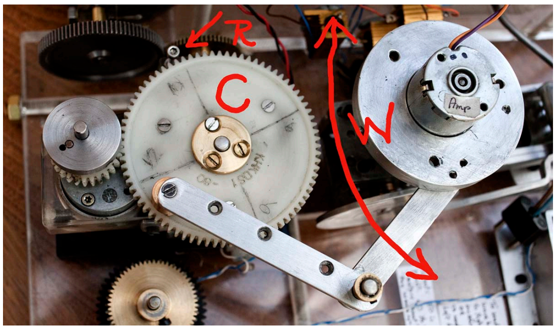


fig118

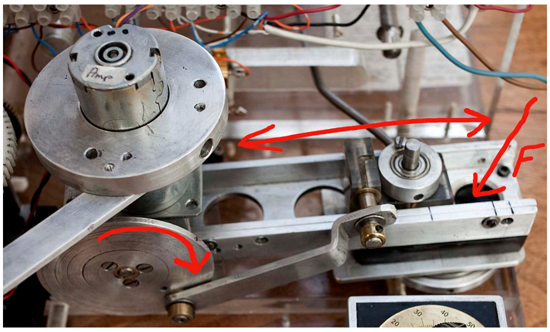


fig119

In fig139 the wheel **C** rotates and drives the wave unit **W** in the directions of the arrow. The drive motor for this is shown on the left. The indicator point at **R** is to allow the wheel to be reset to the same start position at the beginning of a new drawing. In fig140 the extent of the slider carriage is seen with the motion indicated by the straight arrow.

The sliding connection, running inside the 'U' section of the carriage, swings over the fulcrum **F,** fig140 which is a heavy duty ball race, able to take the weight. The amplitude motor on the left hand side provides the drive for the sliding unit. The sliding unit connection, taking the sine wave motion to the double-deck unit, can be seen just to the left of the fulcrum. This connecting ball race moves from a position over the fulcrum (zero movement) to the maximum extent of the slide (left hand position). The varying movement is transmitted along the linkage to the double-deck pen unit. The connecting ball race, situated at the end of the linkage, can be seen at **B** in fig135.

The amplitude motor is seen in the centre of the aluminium annulus and drives a a wheel through a gearbox. It is shown by a circular arrow in fig140 and it moves the connecting point to and fro. A view of the whole unit can be seen in the reference picture fig134 above, to relate the detail to the whole machine. The control panel has switches which can govern the speed at which the amplitude changes; its progress can be either intermittent, fast or slow and continuous. These changes are a part of the programming. So far two sets of interrelated units have been described leading to the drum unit which holds the paper.

The drum unit and differential

fig120

With any machine the paper holder is very important, particularly so with this machine. The drum has a steel strip bonded to the aluminium drum, see middle arrow, and holds the A4 paper in place the magnetic strip shown. To set this up accurately the drum is detachable by a simple lifting action; it rests on two ‘cradle’ bearings. The gear wheel **C** meshes with another on the gearbox unit sited below the sine wave wheel shown in fig139 above. On the left of the drum is seen the linkage to the wave break mechanism, described later. The drum itself is built as a differential gearbox and inside it, as indicated by the dotted line, **D** are the bevel gears. The two rods rotate independently, each can rotate the drum. The gear on the right is the main continuous drive, coupled in exact numerical ratio, to the speed of the sine wave wheel. This governs the number of wave shapes drawn. The left shaft transmits an intermittent drive to the drum rotation, sending it momentarily in the reverse direction. This is detailed in **5e.6**

As the drum revolves, provision must be made to lift the pen up, once each revolution, to clear the magnetic strip. There are two parallel rods running across the machine which pivot in bearings at each side. The larger rod pivots and the smaller one swings in an arc to lift the pen wherever it may be. See the reference picture fig134 where the pen is sitting in the middle position over the drum. The two rods can be seen below the pen tube. The lifting action of the two rods is done by means of a contact disc, fixed to the side of the drum, which operates a lift cam, see **A** in fig141 and in the direction of arrow in fig141. This lifts the pen up, out of the way of the magnetic strip. This cam also sends a pulse, with a micro-switch, see **A** in fig142. This tells the line advance motor to move to the next line by a predetermined distance. The degree of movement is set from the control panel and four inter line distances are available.

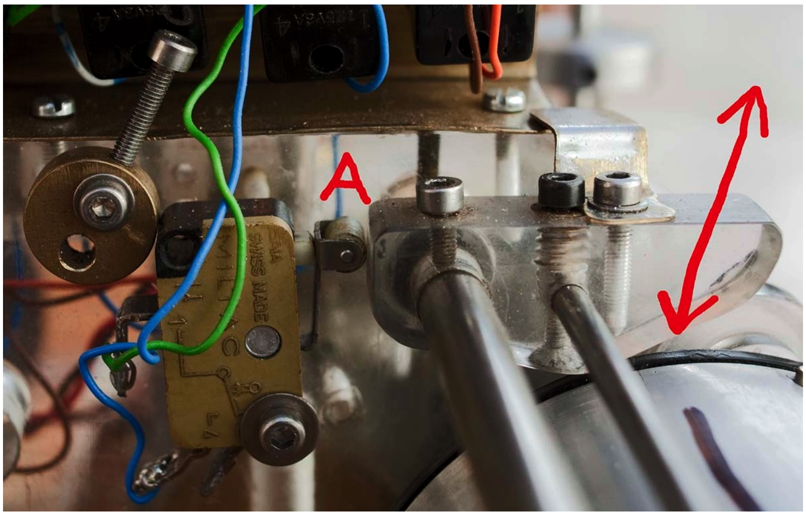


fig121

On the opposite side (of the two pen lift rods) to the cam shown in fig142, there is an identical cam and micro-switch which sends a message to the amplitude motor, telling it to increase or decrease the growth rate of the wave. Alternative strategies are available from the control panel to increase the wave size continuously, intermittently, fast or slow. This takes place either at the end of each drum revolution or at the crest of each wave. This range of programmable alternatives contributes to the variety and richness of the drawings available. The default drum rotation direction is to draw the sine wave shape where the size grows and decays. So that there can be a 'wave-break' aspect to the line, preferably to occur at the crest of the wave, the run needs to be momentarily reversed from its default direction. As the drum contains a differential mechanism it is possible to drive the drum round from the shaft at one end and have a contrary action at the opposite end. To be effective the action must be very fast if a convincing wave-break shape is to be drawn.

Wave break mechanism

The speed of interruption is provided by a dedicated motor, see **C** in fig143 below. The motor runs at a higher speed than the drum and transmits the sudden impulse to the drum shaft through an eccentric profile cam in **B**. This imparts a fast kick to the weighted rod connected to the second drum drive shaft. For accurate reset purposes the location point is shown at **A**. Finally the whole wave break mechanism is put into operation by switching on the dedicated motor which runs at a near synchronous speed[1] with the main drive motor being of identical design.

An alternative strategy would be to trigger this action from the wave crest micro-switch currently coupled to the amplitude growth system. This would entail a solenoid operated linkage in place of the motor; a possible modification for the future. A small advantage in the present set up is that the exact placing of the wave break can be varied by slightly altering the speed of the dedicated motor with a variable resistance. The limitation of the present system is that wave-break, using a motor, only works when there are six wave forms as the sine and wave-break motors only synchronise under this setting. Changing the number of waves, with a different sine wave to drum speed ratio, spoils the wave-break shape. Fewer waves means a smaller shift in direction through the differential. The solenoid operated linkage mentioned above would eradicate this problem.

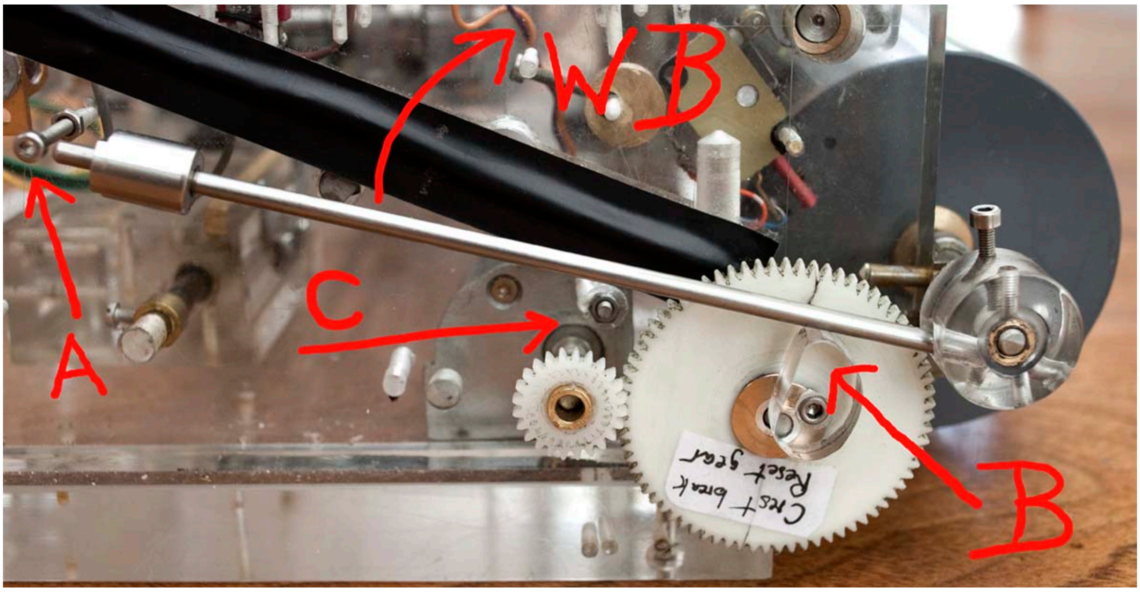


fig122

Note 1. *Most quality D.C. motors, under reasonable load conditions, run at similar speeds.*

Pen lift device

The pen holder already has a lift facility to allow the magnetic paper holder to pass unhindered as the drum revolves. A pen lift device was therefore easy to fit by coupling up to this mechanism. The pen lift is done by a separate motor mounted on the top of the pen lift carriage. This is seen at **P** in fig134. The motor shaft has a simple cam attached, which through a flat brass linkage raises and lowers the pen. Again the pen motor runs in near synchronisation with the drum drive motor and the frequency of the pen cycle is governed by the numerical ratio 1:17 to the drum speed. Images are shown below demonstrating the wave breaks and the pen lift effects. The combination of the various programmable effects offers a very large number of alternative images with variety and richness.

Slope control

A further mechanism is available as an alternative to the wave-break system. This is a slow gearbox attachment to the drum and replaces the wave-break linkage in fig144 below. Its purpose is to cause the waveform to slope as opposed to being vertical. The effect is at its best when the number of waves is high,i.e five rather than two or three; creating steeper slopes.

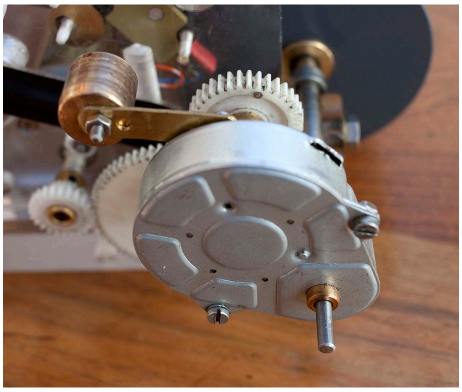


fig123 'slope' drive to differential

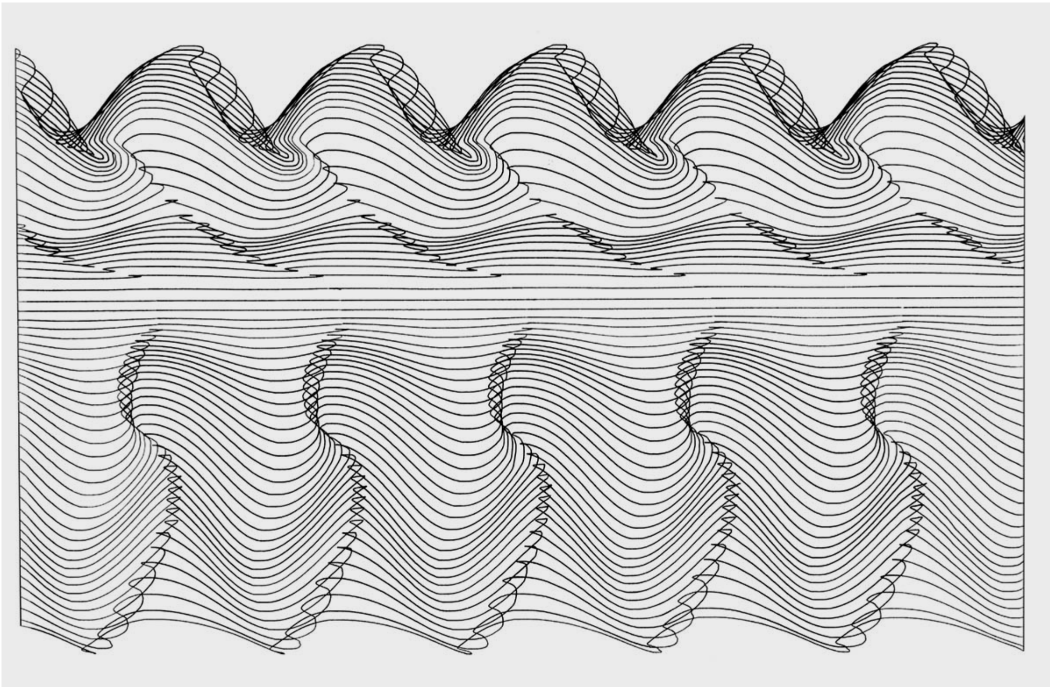


Fig124 wave break image with sine wave growth and decay and five waves

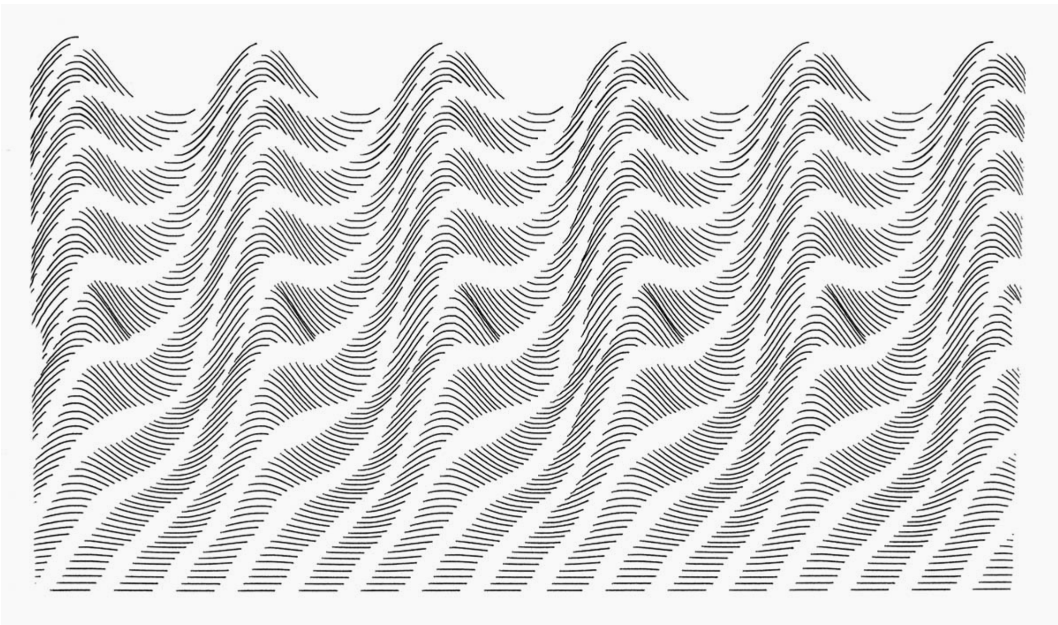


Fig125 shows pen lift in operation with wave growing from zero to maximum

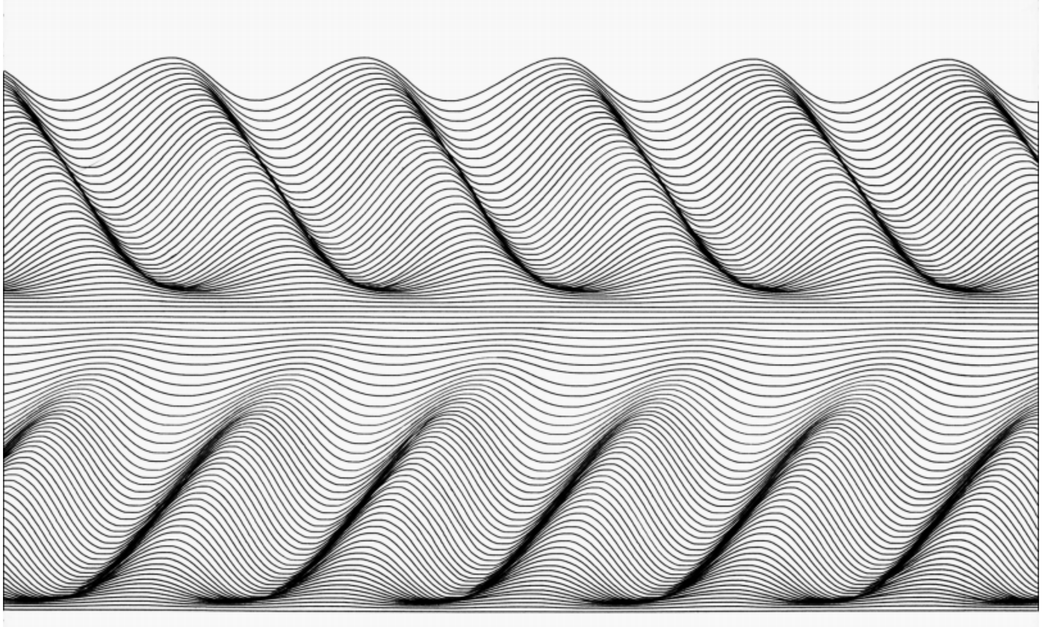


Fig126, drawing with 'slope' attachment in place

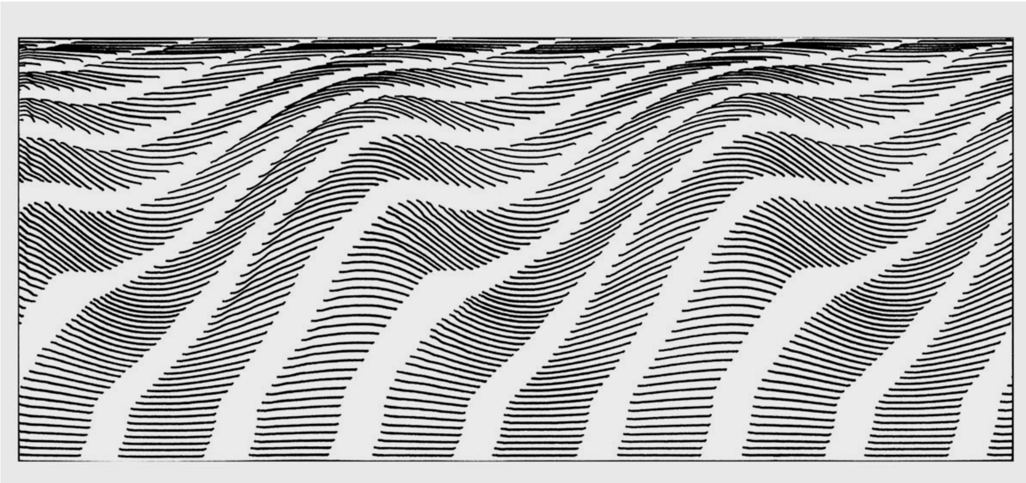


Fig127, pen lift at a different ratio; a slight difference in motor speeds cause lateral movement.

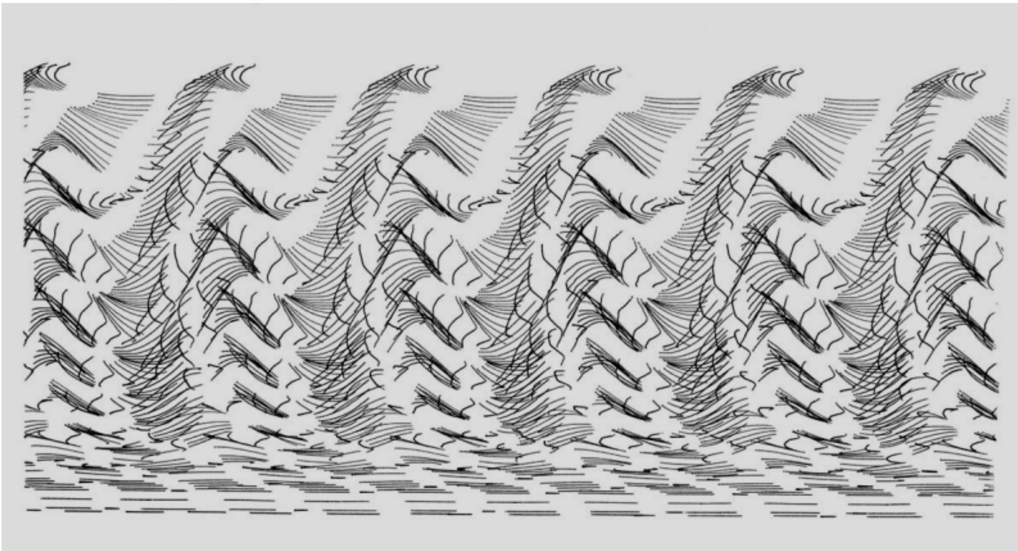


Fig128, shows a drawing with combined pen lift and wave break settings

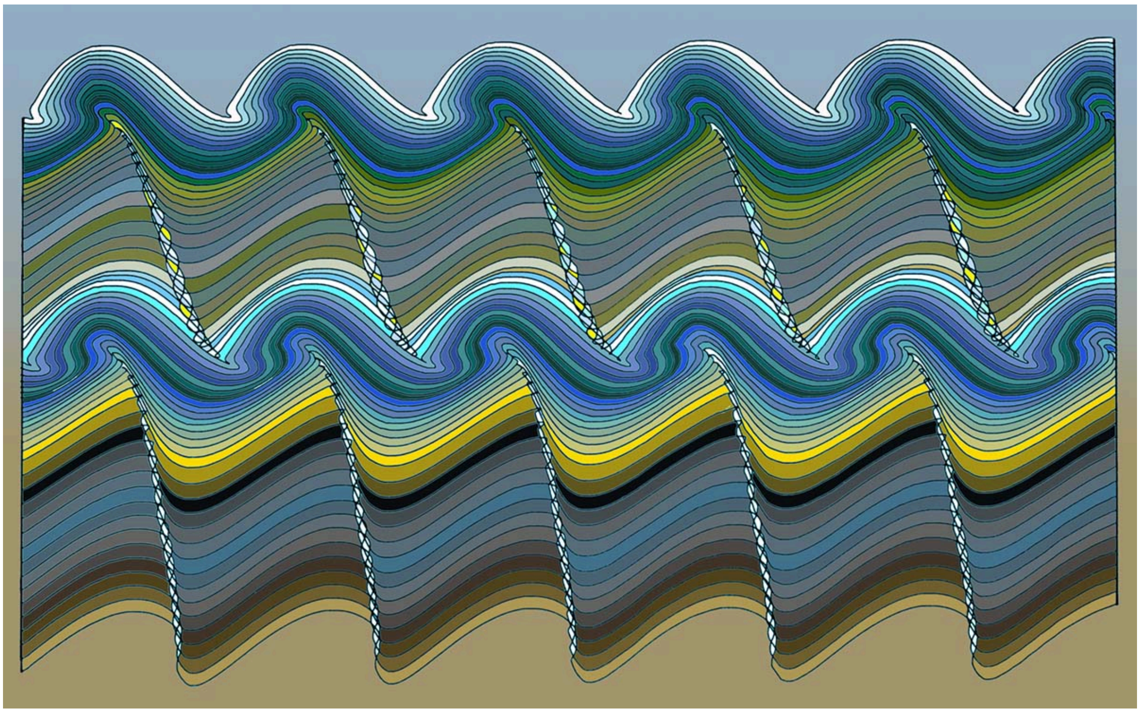


Fig129, shows Photoshop afterwork on a wave break image

Control unit and programming

Fig130, Control panel allowing internal programming in conjunction with gear changes.

Concerning programming, the Sine wave machine stands midway between the Linkogram and Meccanograph, where the programming is simply adjusting gears and linkages, and the NSEW, NSEWsp and Scribblogram examples which cannot function without a programmer. The Turntable differs from the rest in that it can function as a stand alone with some inbuilt programming but may also accept programming from a timer, in that the individual motors are addressable separately. The Sine wave is dependent on the accurate interrelationship between the sets of functions outlined above; external programming is inappropriate.

The following functions are variable and can have their characteristics changed by the switch positions. There is one main 'on and off' switch and two for resetting.

The latter are for setting the start position when a drawing needs to be repeated with some accuracy. There is also a switch at the other side of the machine switching in the wave-break mechanism. Three other switches control waveform amplitude and pen lift and two more adjust line separation. If necessary the reset switch may be used in the programming to run the amplitude motor continuously.

The amplitude control is solely concerned with the speed at which the wave shape grows and decays. The pulse for the amplitude motor can either be taken from the drum micro-switch and advance the growth once each revolution, or taken, via another micro-switch, from the crest of each wave. This results in the wave shape growing a number of times for each revolution. Both these can also be combined to make the growth faster. The remaining amplitude control governs motor speed by fixed value resistors. This simply causes the growth from the input pulse to be fast or slow. There are **6** permutations available to adjust the wave shape. This increases to **48** overall if the pen lift and wave break are included without counting the line adjust features.

The precise spacing between the lines is crucial to the aesthetic qualities of the drawing. It varies from a very close or fine setting where the lines can touch at some points to a wide space equivalent to ten times the line width. The preoccupation with interline spacing is common to other machines such as the Linkogram, Meccanograph, and in some instances to the Turntable and Scribblograph. Line spacing with line smoothness, are defining factors governing the expressive effect of the drawings. There are **4** settings for stipulating the inter-line space on this machine, achieved by employing two two-pole switches. Adding another **4** variables, brings the total of permutations to **48 x 4 = 192.**

Further variation is possible if the number of waves in the line is altered. Whilst this is not as easy as throwing a switch, the facility exists to changes the gearing between the sine wave wheel and the drum speed. The gears to do this are stored on the machine bed and may be seen in fig134 indicated by the letter **S**. There are currently **3** gear settings. Finally there is the 'Slope' attachment to take into account in the catalogue of possible variations as well as the wave-break motor-speed trim facility. This trim facility operates best when the number of waves is six and there is a synchronisation of speed between the main sine motor and the wave-break one. The purpose of this adjustment is to control the placing of the wave break effect as near to the crest of the wave as possible. It will vary when the motors get slightly out of step owing to what is termed 'hunting'. This tends to increase the pseudo-random proportion of the overall programme.

In total there are approximately **192 x 3 x 2 = 1152** permutations theoretically possible although in practice some will be very similar and some will not be interesting enough to pursue[1]. However, sufficient alternatives exist to support the claim that the programming allows room for creative manoeuvre.

Summary

Whilst the description of the workings of the Sine wave machine has been detailed and complex, it illustrates the interdependence of the components and sets of units, typical of design activity. The intent to reproduce sine waves is clear; enhancements to the basic sine shape follow a logical path. Furthermore, problems posed and solutions found are evidence of analysis and decision making and are demonstrated by the results. With programming, the choices are similarly logical. The large number of permutations offers scope for creative outcomes. Other machines employ similar design procedures but are not detailed to the same extent as they are mechanically simpler. The Sinewave machine represented a much more difficult challenge than any other machine; on a level with the problems solved in the design of Timer 4 which approached a quasi digital level of programming facility.

Note to Sinewave machine in general

The criteria employed in selecting a drawing rests on the formal properties of the line to line relationship and whether the overall drawing has a coherence which exploits the underlying sine wave shape. The evaluation is also influenced by reference to the 'fuzzy notion' of the original intent. This was present at the outset where the question arose of how a sine wave shape might be explored as the topic for an artwork. Clearly these are individual subjective decisions but experience has shown it is easier than might be expected to select images for further work. It might be interesting to compare the results of the analogue Sinewave machine with those from the Hewlett Packard computer plotter, in particular fig ??? Different routes have led to the same destination in terms of resolving intent.

Turntable machine

The intent

The intent, in designing this machine, was to combine the sinusoidal motion developed in the Linkogram, Meccanograph and NSEWsp machine, together with the rotary motion of a turntable, concentrating on circular as opposed to rectangular images. Regarding programming it is a hybrid. The aim was to build a machine programmable by external timer but incorporate a sufficient variations to enable it to be programmed internally. In this respect it differs from all the rest of the machines. It shares some characteristics of the Meccanograph and Linkogram but is different enough to extend the range of drawings in ways not possible with the others. Part of the way through its development, at the Mk III stage (see below), it was redesigned to be used with a light pen unit as well as a graphic pen. It was at this point that the sun and planet mechanism was added (successful in the NSEWsp machine).

Initially the machine was rebuilt at an angle, canted over to facilitate the used of a digital camera to record the light pen unit. When an angled turntable could not carry the weight of a large digital camera the design was changed. When the camera rides on the turntable,i.e. in the role of the paper and the light is placed above the camera then the drawing geometry is the same. However if the light pen unit sits on the turntable with the camera above it the geometry is opposite, and creates a significant difference to the images. This difference in geometry is explained in detail on p107, and illustrated by the light drawings, figs 164&5. In fig164 the camera is on the turntable; whilst in fig165 it is above with the pen unit on the turntable.

For better ergonomics the machine was rehoused and significantly modified in the latest Mk lV version. Recent designs have encased the machines, refining ideas which have existed for some years. The Turntable machine, light unit, NSEWsp and Timers 3&4 are examples. It is not intended to go into mechanical detail in following machines. The Sine wave machine was an amalgam of earlier reliable systems and depends for its effect on precision, accurate bearings and absence of backlash.

The earlier machines Mks l+ll

With the first two machines a number of configurations were tried going towards a refined idea. It was only at the stage when the sun and planet mechanism was settled on that the design began to develop. This direction was likely to produce drawings which were interesting, different, with the chance of an extensive repertoire to justify the time and effort. Each new machine takes many hundreds of hours to develop to the stage where it contributes to the overall purpose. As the smallest components often have to be made from scratch, engineering fitting is particularly drawn out. An additional task was to design a rotating multi-pen unit so that it could mimic the output of the light pens and enable graphic prediction of the light drawings. This proved difficult but was eventually realised in the NSEWch machine and it also become available to the Turntable machine.

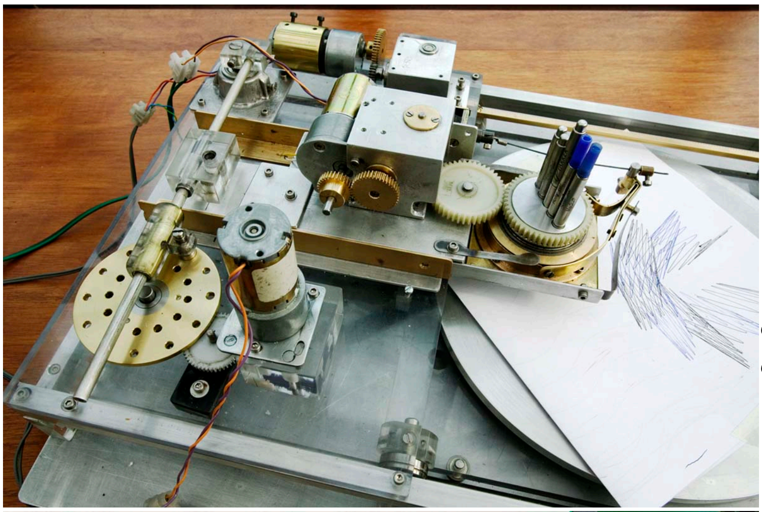


Fig131, the Turntable Mk I is an unresolved design before the sine wave drive was fitted.

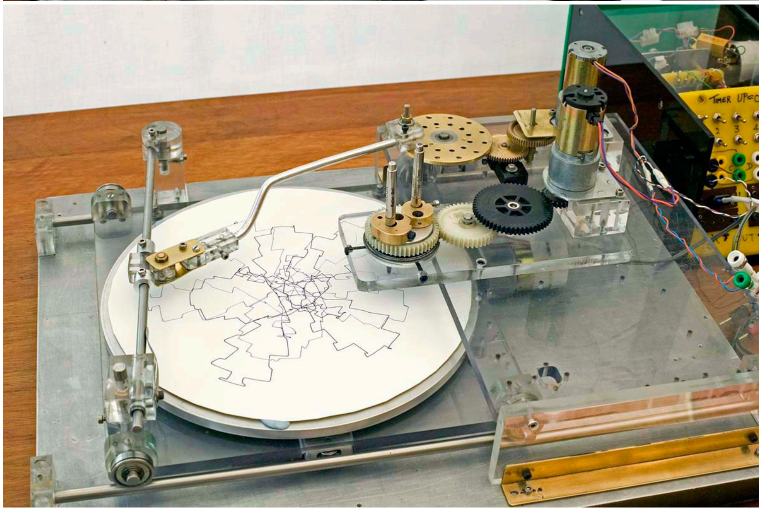


Fig132,Turntable Mk ll with Programmer top right. It had an unsatisfactory X axis drive which was not only non-linear but suffered from too much backlash.

In these machines various ideas were tried which combined sinusoidal with circular motion. In both, the turntable was built to run on precision ball race bearings. In Mk l it had a rack and pinion drive to provide a slow progression to run in conjunction with the sinusoidal motion of the pen carriage. In addition a solenoid operated pen lift was fitted. In Mk ll all three of these mechanisms were abandoned; the turntable's sinusoidal motion was done with a linkage and the pen carriage became a fixture with no pen lift.

The purpose of the above detail and description is to add another dimension to the design process. In my experience of this, the path to a final simple machine has never been a direct one. Here the intent was not well enough formulated, as with the Linkogram and Sinewave machines. The penalty was a longer route to the present configuration. The helpful feature which did survive these changes was the rotating pen device. Although the multi-pen set up did not work at this point, it led to the design of a combined pen lift and rotary motion; eventually made to work on the NSEWch machine.

In both Marks l&ll the basic turntable revolving motion was done by a friction roller drive (rubber on aluminium) where the motor was placed under the platen; this solution remained throughout with slight modifications proving more accurate than expected.

The Mk lll machine. Problems resolved

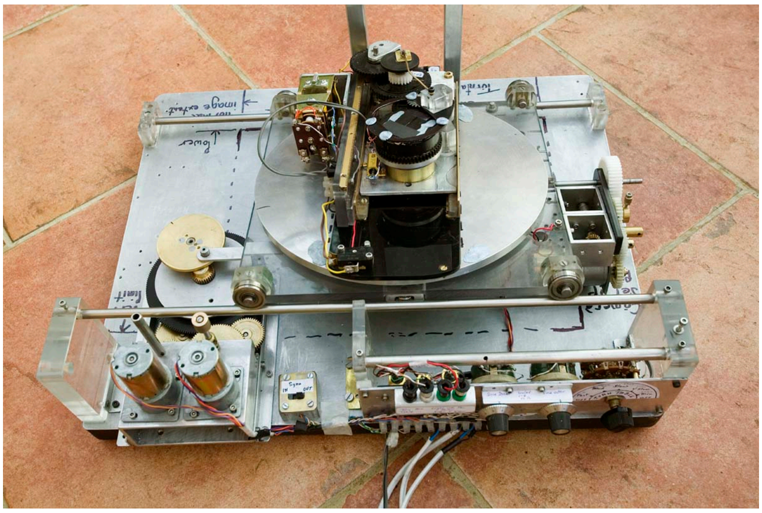


Fig133, Mk lll Turntable machine now has a sun & planet sine wave drive combined with a new light unit, both of which made a significant improvement to the drawings.

The form taken by this version shows that all the problems of direction, lacking in the earlier ones, had been solved. The turntable unit was canted over, the sun and planet sine wave drive fitted, a light pen unit was added with the D.C. current led to it through the turntable. The control panel has a potentiometer speed adjustment for each of the sine wave motors whilst the turntable has a two speed gearbox and the multi position switch with a resistor bank to govern its speed. Provision was made for the light pen unit to be replaced by a rotating pen device and a bracket made for the attachment of a digital camera. This machine functioned well; the chief reason for its redesign was partly cosmetic, partly to reduce size and weight and to make provision for the camera to ride on the turntable. The differences seen in the Mk lV machine illustrate the progression from a working prototype to a refined model, smaller, lighter, with a better appearance and easy to understood if used by others.

The Mk lV Linkogram

Like the latest version of the Linkogram, the progression of this machine went from lab prototype form to a modular design. The brass plate housing contains all the units, keeps them dust free and the control panel is put in the correct ergonomic position with a simple layout. In addition the light pen unit has undergone a complete redesign being similarly simplified, lightened and housed in black aluminium cladding. At this stage the machine is beginning to look as if it were designed rather than being an ad hoc collection of units tacked onto each other.

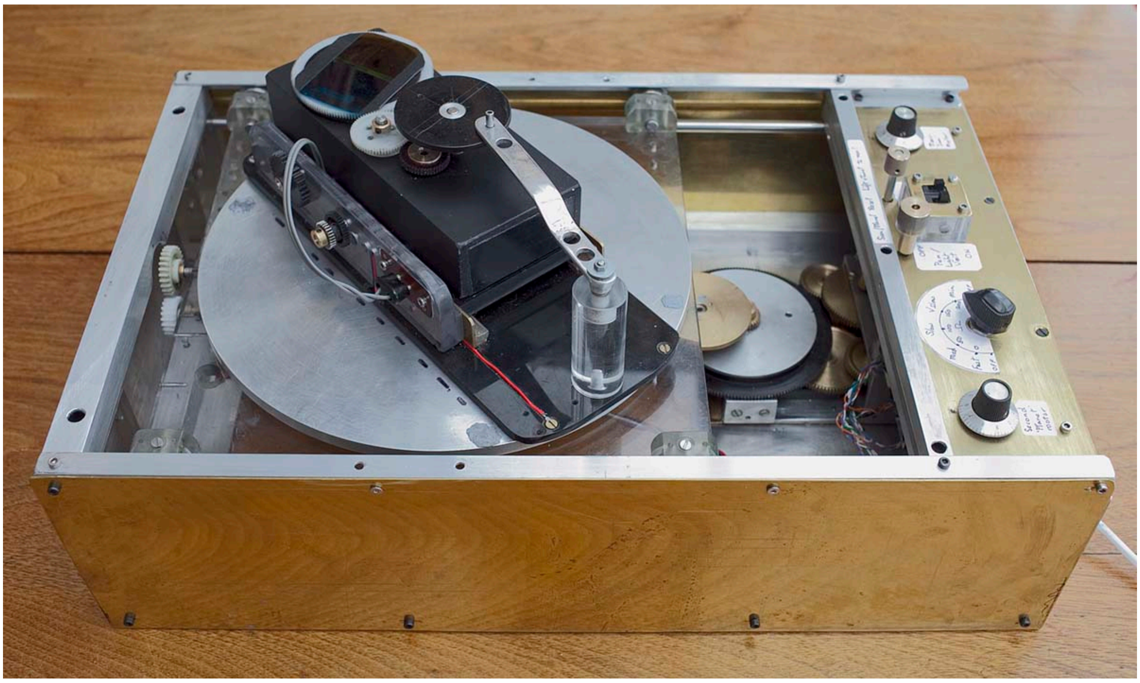


Fig134, the Mk IV Turntable with improved (from Mk III) rotary light pen colour-changer .

As far as I am aware this is typical of the design process generally. This machine has very recently been tested for its function in light drawing configuration in the state shown below. It may also be used hooked up to a timer which by-passes the internal programming in favour of separate instructions to the two sine motors, turntable motor and light pen unit. The effect of this is to veer away from the sinusoidal character of the internal settings and offer a type of drawing similar to that of the NSEWsp machine except that the general form will be circular rather than rectangular.

Summary of motions available

The range of motions which may be combined on this machine to produce a very large number of alternatives they are as follows:-

1. *The circular movement of the turntable with ten different speeds.*

2. *The main sine motor, being a sun and planet mechanism, turns both the main wheel and the secondary wheel even when not driven by its dedicated motor. This is because the secondary cam is connected to the centre pinion by the large brass gear visible in the illustration below* ***5f.7****. This motor also has variable speed.*

3*. The secondary sine wave motor drives the small pinion at the centre of the main wheel influencing the rotation of the second input relative to the speed of the main wheel. This secondary motor is also subject to speed variation. The two sine wave motors can either be locked into* *synchronisation by means of a switch on the control panel or switched out. When 'in sync.' the combined effect of the two motors is to cause the sine wave to grow or decay very slowly. The two motors are always slightly out of phase so they move slightly relative to each other, allowing the amplitude of the swing to change during the progression of the drawing. When the two sine wave motors are not 'in sync.' amplitude change occurs quickly. By means of the individual speed adjustment, coupled to the 'in or out of sync.' state, a number of permutations may be set.*

4. *When the light unit is fitted, this runs on a track, moved to and fro by a cam along the radius of the turntable. Within the light unit there is a rotating slit image, which may be driven at one of three speeds. Set above the rotating slit, moving independently of it, is a rotating filter wheel able to be set at three different speeds. It may revolve in the same clockwise direction as the slit-image or contrary to it. This relationship governs the speed at which the colour of the slit image changes as all the motions interact.*

The extent of choices

The number of alternative settings is large; there are many potential creative strategies with internal programming alone. The range increases when an external programmer is brought into play together with pen motion. It is difficult to put a precise figure on the range, due to the variables of filter sets, pen motions and start positions. However it is close to 500,000 without counting the external programmer. If this is included the number runs into millions. Whilst the number may be indeterminate, enough variation exists to accommodate a variety of approaches; particularly if the machine were to be used by other artists.

The conceptual significance is that such an analogue machine may be compared to a computer controlled digital device concerning its balance of 'chance and order' strategies. The 'process advantage' of analogue is simplicity and transparency. The sequence of decision steps can be outlined in easily understood terms; not requiring technical expertise. The results show elementary actions generating complexity. More ‘coherent’ images emerge than might be expected from what could be regarded as a potentially chaotic process.

Drawings with light pen, with and without external programmer

The pictures below are a few examples of the results so far with this machine. Some of the images show similarities with those from other machines where there is an inevitable crossover when sinusoidal, circular, and Cartesian co-ordinate motions are involved.

Figs135 & 136, the Turntable machine accepted instructions from external timer

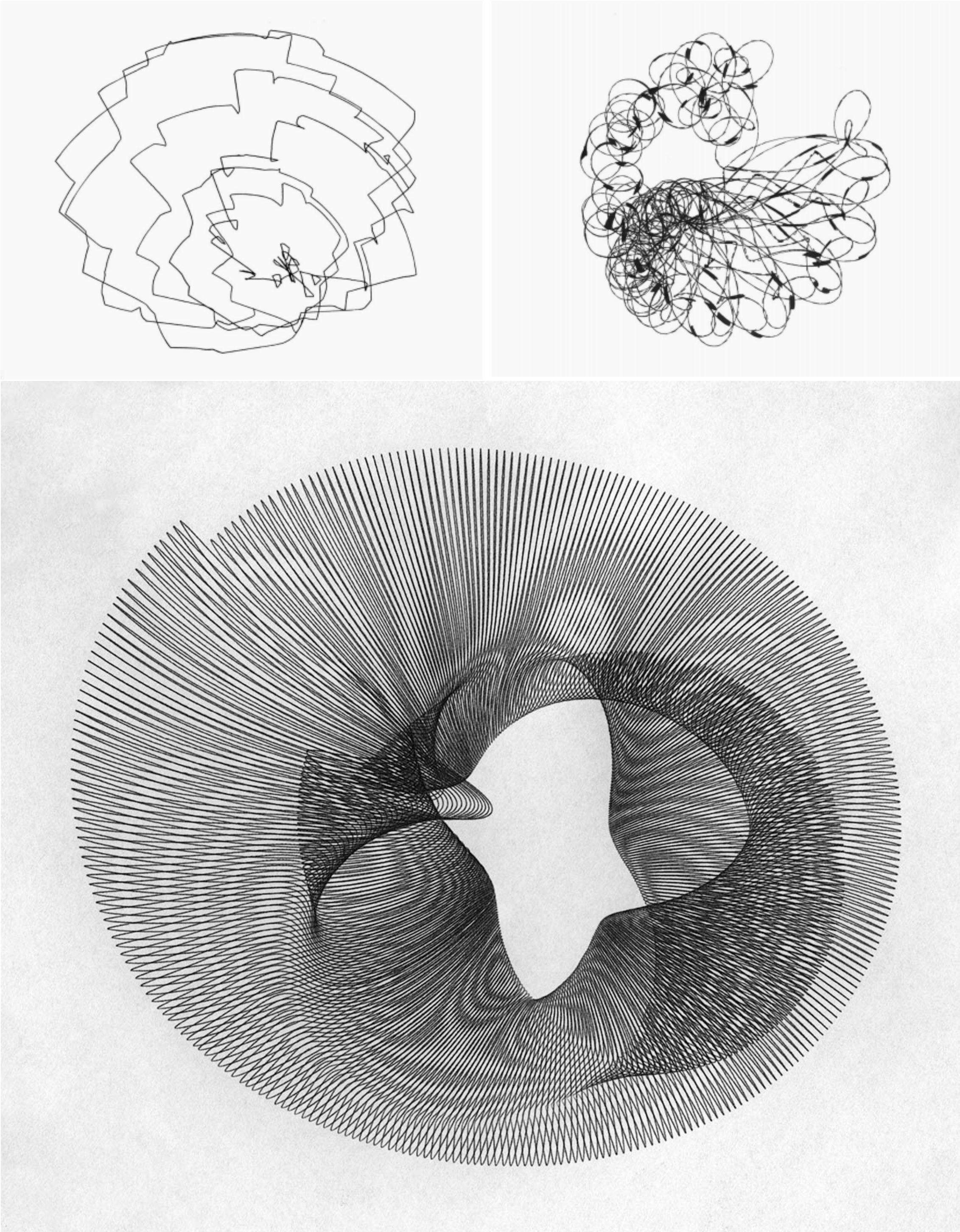
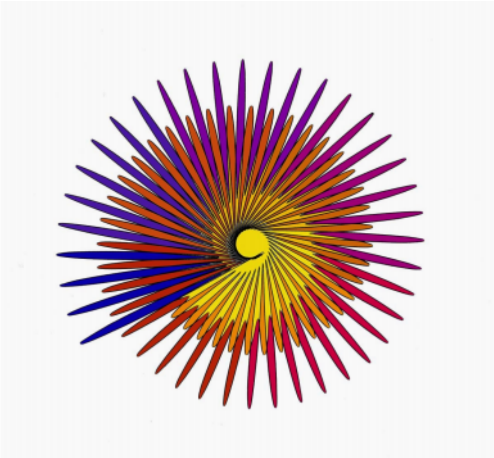


Fig137, a very slow turntable speed and relatively fast sun and planet drive.
This is similar to Linkogram drawings; both have turntables and close lines.



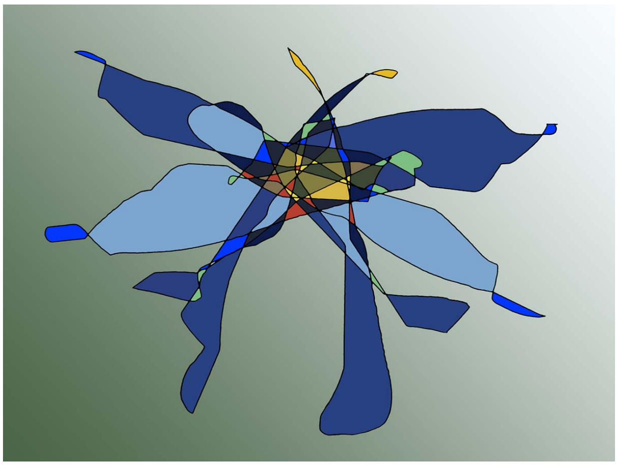
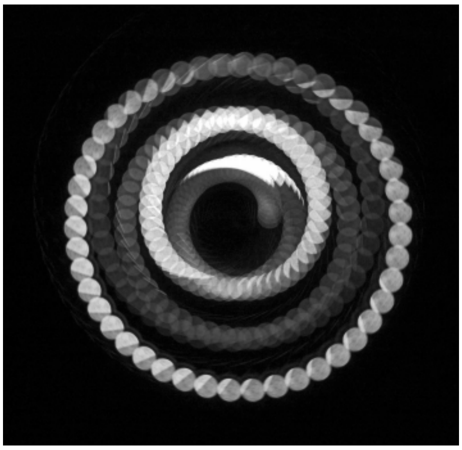


fig138 fig139

Fig138 has a slow turntable speed with simple amplitude variation from the sun & planet drive. Fig 139, is a drawing where all motors are subject to Timer 1 control. Colour added in Photoshop.



Figs 140 &141, light drawings with different 'pen' shapes using a fast shutter mechanism

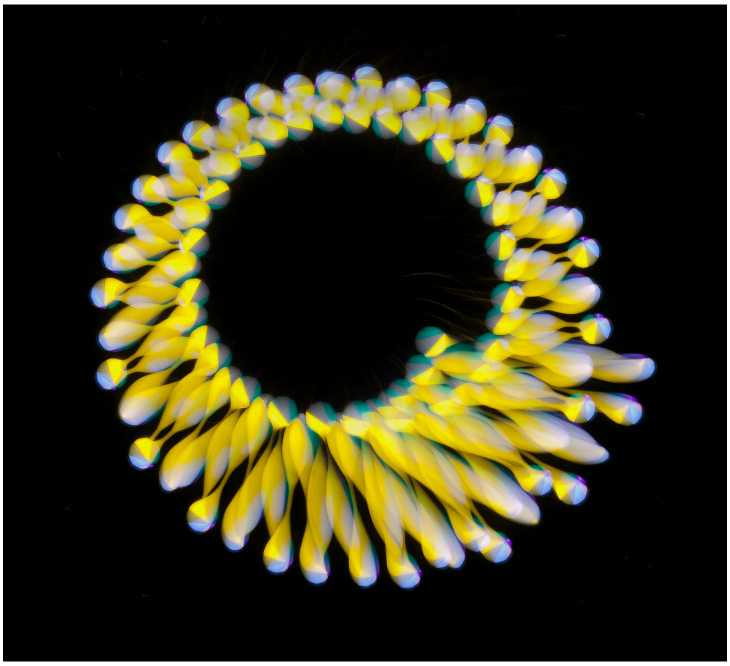


fig143

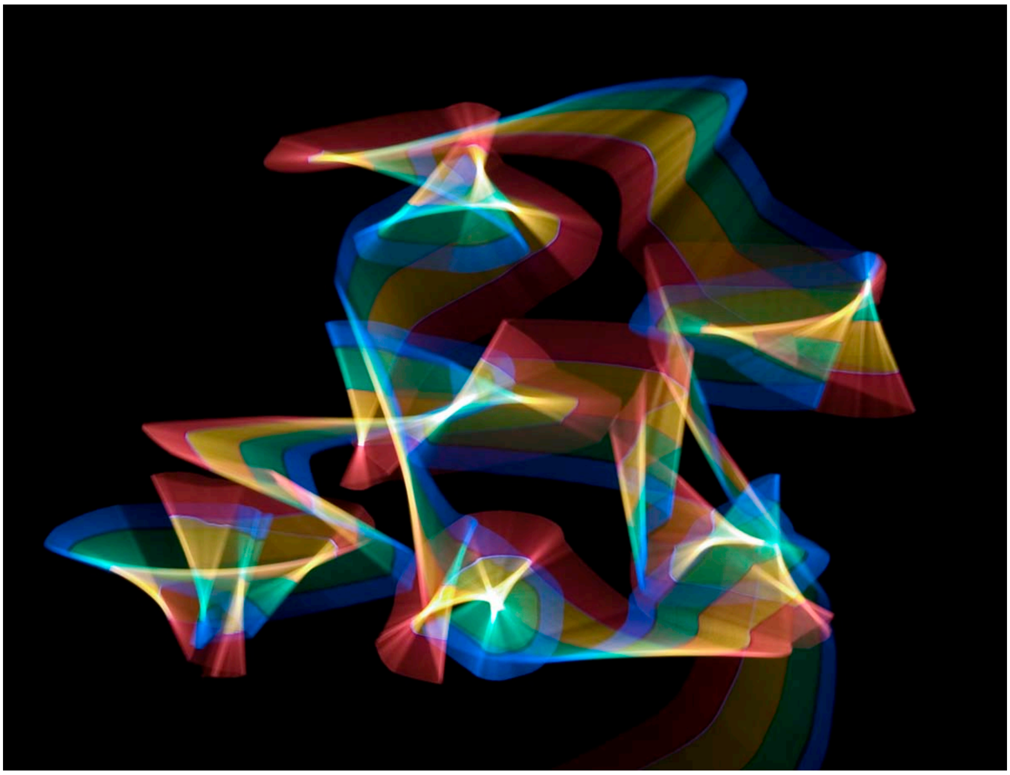


fig144

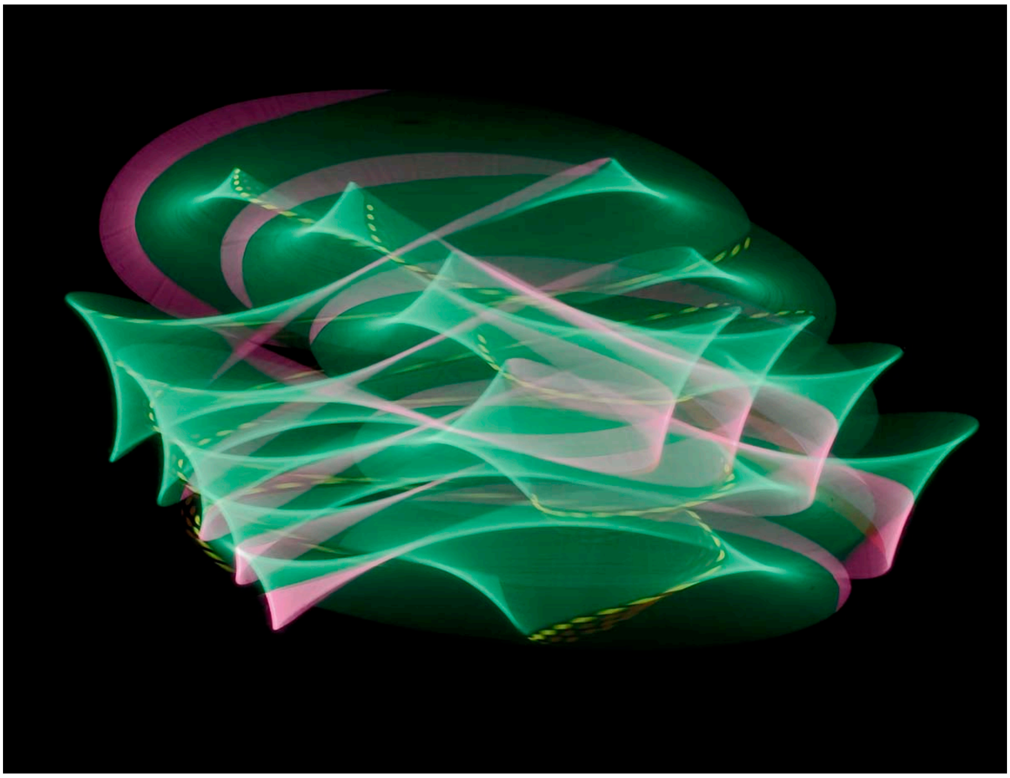


fig145

Figs 140-148 show differences in geometry between camera and light positions. In two only, figs143 & 148, the camera is on the turntable with the light above and programming is external. In the rest, figs 140,141, 144-147 the camera is above, with the light pen on the turntable and programming is internal. All have colour changers available but figs143 &148 have a variable-size *light source above the turntable. In the others the revolving-slit light source is small enough (see fig91 pg 58) to fit on the turntable as it turns with the camera and shutter unit placed above.*

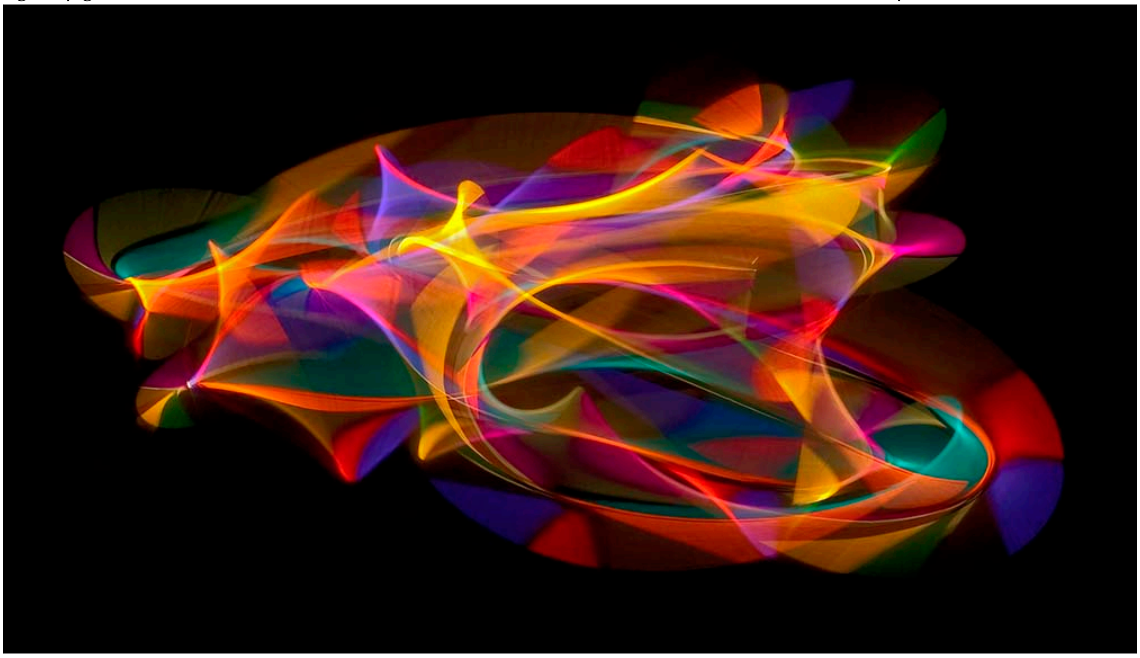
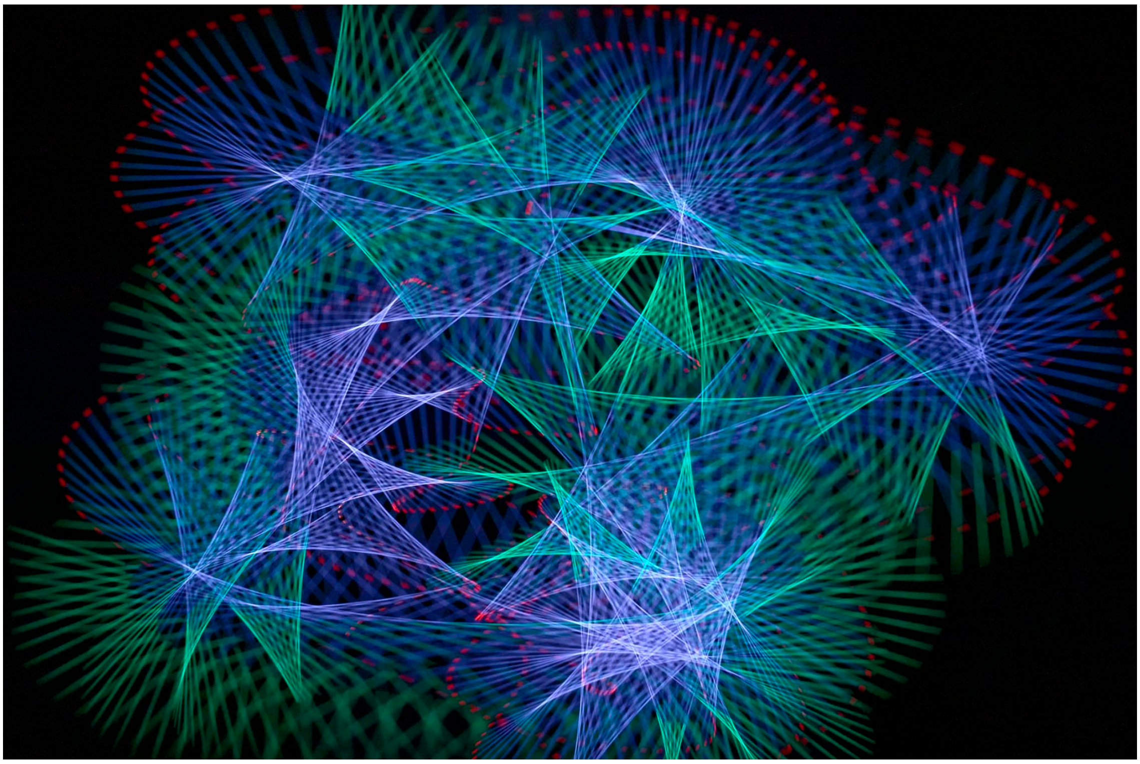


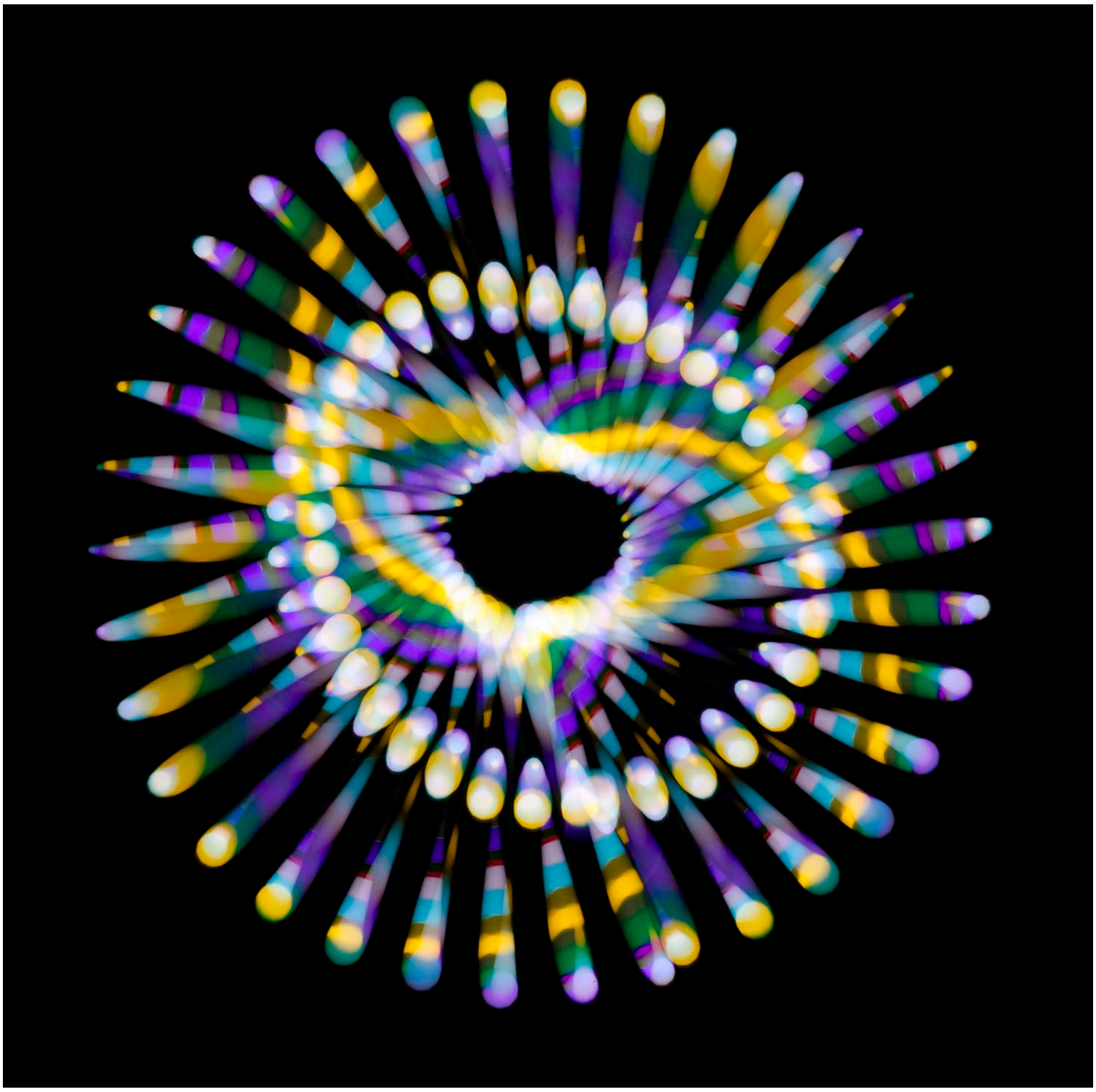
fig146

Figs166 &167 are two more examples of drawings with the light pen situated on the turntable. Figs162,163,165-167 show the results possible with the machine's internal programming.



In fig147, above the camera is situated above the turntable with a shutter in action. The light source was a large revolving slit and the Turntable machine was programmed internally.

fig148



In fig 148 the camera was placed on the turntable using a variable size light source with colour changer situated above the machine. It and others represent turntable usage contrasting with the camera being placed above the machines as in figs140,141,144-147.

Summary

Given that the Turntable machine was designed to exploit circular images, as the name implies, it has made a significant contribution to the range of machines and the character of images available from them. When using the basic movements (turntable and sine wave) the circular motion tends to dominate the images but its effect is lessened if an external timer is used to control the machine.

It is the only machine to combine external and internal programming. This makes it versatile; from recent work, following the latest rebuild, it has a major role to play. It is particularly suitable for use with the light pen unit; is reliable and easy to use. The turntable machine has recently been extended. A gantry for either a light unit or digital camera has been made with an integral shutter and colour change unit. The position of the camera and light pen unit can now be switched. The digital camera can sit on the circular turntable and the light operate in a static position above. The chief advantage of this is that the character of the drawn images may be more closely reproduced in light. 'Sketches' can be made by pen and then reproduced as light drawings once the particular settings proved encouraging. It has fulfilled the aim of becoming a design tool able to use pen or light. Regarding conceptual progress this allows a smooth progression between intent, production and evaluation. With this machine it may possible to explore how art process works, as a result of its adaptability and range of images, together with its user friendly character.

Scribblogram

This machine, an A3 size X-Y plotter, is larger than all the others in the size of drawing produced. It follows on from the NSEW initiatives and extends the scope of this type of device. It was built to do three things:-

a. To accommodate a cross hatching drawing unit which needed an A3 size platen to give the 'scribble unit' enough room.

b. To test a linear drive motion by means of a heavy duty chain and pin system. This required a large machine to enable it to be built.

c. To make a machine strong enough to carry the weight of a large revolving light pen to be fitted in place of the 'scribble' unit.

The machine is designed to facilitate images similar to fig147 to be recorded on a digital camera; hence the canting over of the rig for easy tripod use.

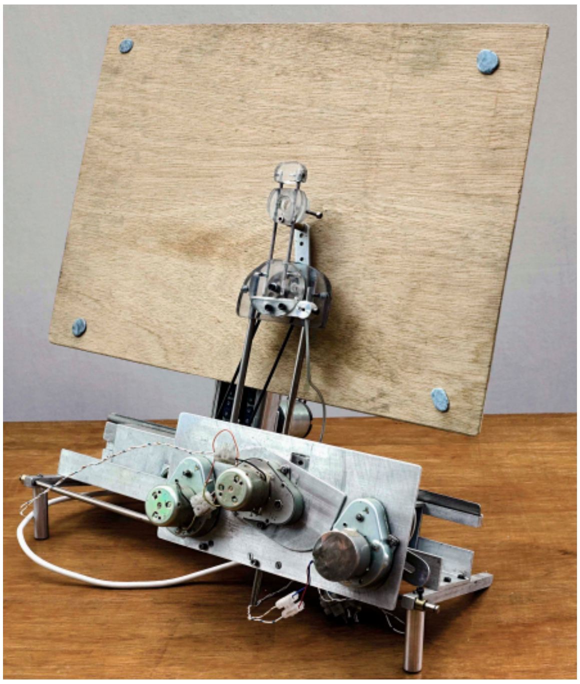


Fig149 shows the Scribblogram in graphic mode with cross hatching rig on the A3 board.

Cross hatching

All previous drawing machines had concentrated on a relatively simple drawn line, either continuous or broken when the pen was lifted. Following the success of the NSEW machine, in conjunction with the rotating pen and pen lift unit, the aim was to carry on with the idea of *"Go to a co-ordinate and then draw something"*. The Scribblogram depends on an external timer to operate it and because of the larger number of outlets required it became necessary to add to the timers. The current ones were built with two main outlets, two each for X and Y axes respectively. Four separate outlets were needed and now are built into all the redesigned timers.

The cross hatching stems from the hand drawing action of tonal shading using multiple cross hatch lines and the unit was made to mimic this. The current machine satisfies this to a limited extent and there are plans to develop this notion further. Presently the cross hatching has sets of curved lines which draw at different angles. This is not as good as I would like; more work is to be done to design a unit which draws straight lines at right angles.

Fig150, Scribblogram with pen down, tracing the co-ordinate path and cross hatching.

A robust linear chain drive

As mentioned in above the type of drive chosen has a bearing on the drawn outcome. As the problem associated with a linear drive is in the return mechanism; various solutions have been tried to make the device simple, elegant and reliable. The Scribblogram uses a chain loop driven at one end by a toothed sprocket with an idler sprocket at the other. As the chain is large and heavy duty the bearing pins joining each loop are equally large; 3 mm in section. It is possible to replace and extend one of these pins, which then engages with a slot in the X:Y carriage driving it to and fro when the pin passes round the sprockets.

This solution had been envisaged previously but was attempted with belts which were not satisfactory. Here the scale of the drive was increased and a robust chain used. (Following the success of this version a later machine, NSEWch Mk Vll, was fitted with a smaller chain drive system, see **5d**) This mechanism has been more reliable in practice than any other earlier system, where relatively elaborate latch-relay reversing and micro-switches were employed. A chain drive, being mechanical, avoids problems of electrical contacts and 'delicate to adjust' spring loaded devices. Whenever a machine has failed in the past it has always involved this aspect. When it occurs, particularly during light pen usage in total darkness, much time is wasted. It was this problem which prompted the recent redesign of NSEWch (MkVll). It proved impossible to carry out an exploration of drawings called for by this study without total reliability.

A vertical design

All previous machines were conceived as horizontal set ups. In this case it was decided for space and 'footprint' considerations to design a vertical rig. See figs170,172&173. An additional advantage of this was that it would be easier to use in light pen mode as the camera could be set up in an 'optical bench' configuration. When the machines are operating as horizontal units, they are easy to use with graphic pens but difficult in photographic mode. The camera has to be suspended over the centre of the machine, using a tripod to do this is not a good solution. A special raised platform, an adapted enlarger, has now been built to address this problem. It is possible that this might render the Scribblogram superfluous particularly if a new cross hatching device is built which could be used on a number of machines.

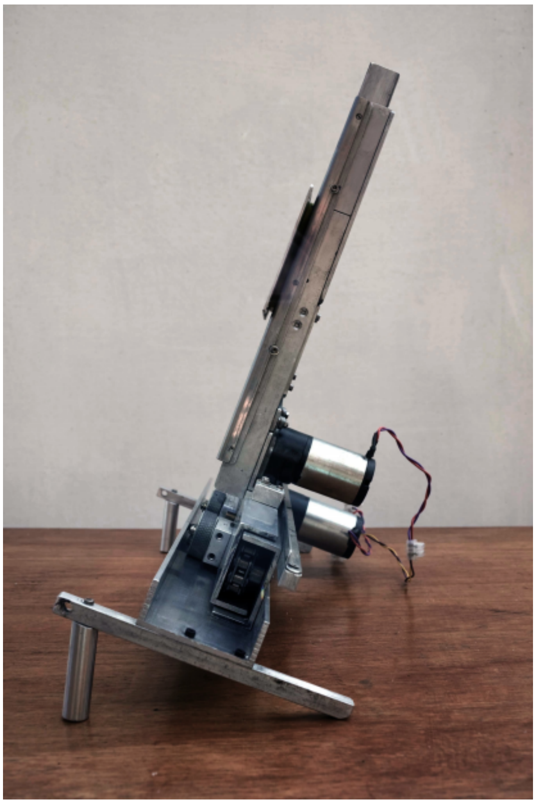
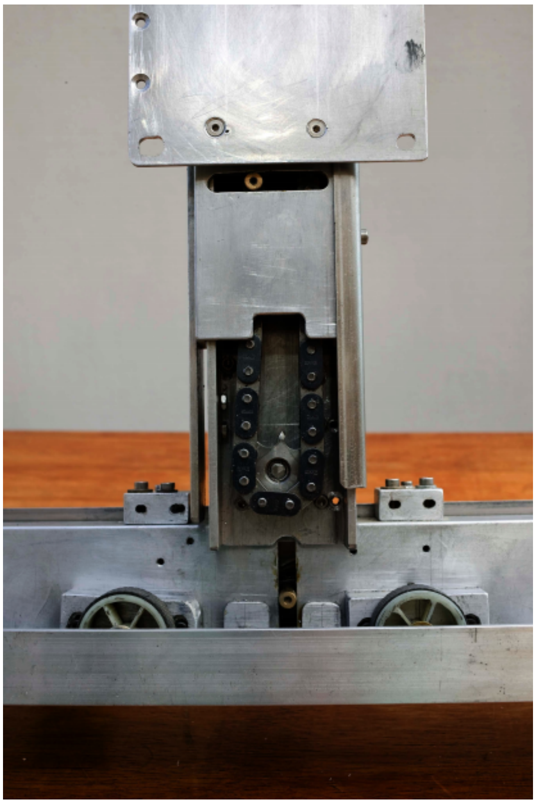
 

Fig151 shows the canted layout; fig152 illustrates the Y axis chain drive and X axis wheels

The basic mechanics of tracking

The first construction problem to be solved in any X-Y plotter is the type of track mechanism on which the X and Y carriages are to run. In other machines such as the NSEW, NSEWsp, Sine wave and Meccanograph at least one axis, but usually both, have run on steel rods, employing either ball race or pulley section wheels to keep friction to a minimum and to ensure precision. In the Scribblogram machine, in vertical mode, it was decided to use a telescopic slider device for the Y axis and a channel slider for the X axis. The sliders and channels not only acted as guides, with ball race or wheels to allow smooth movement, but also provided covers for the chain and pin drives. They had to be well lubricated and if not covered would attract dust.

Platen and light unit interchangeability

The larger size of this A3 unit meant that the drawing platen, to hold the paper, had to be four time the area of those in other machines. Whilst the layout of the machine was vertical it was built with a few degrees of leaning back. This angle was to create a slight gravitational pressure for the cross hatching pen and allow for easier alignment of the camera when used as in light pen mode. The large A3 platen was in this case made of very light plywood and was attached to the Y axis upright by a simple pin system. With this pin set up it was easy to exchange for the larger light unit.

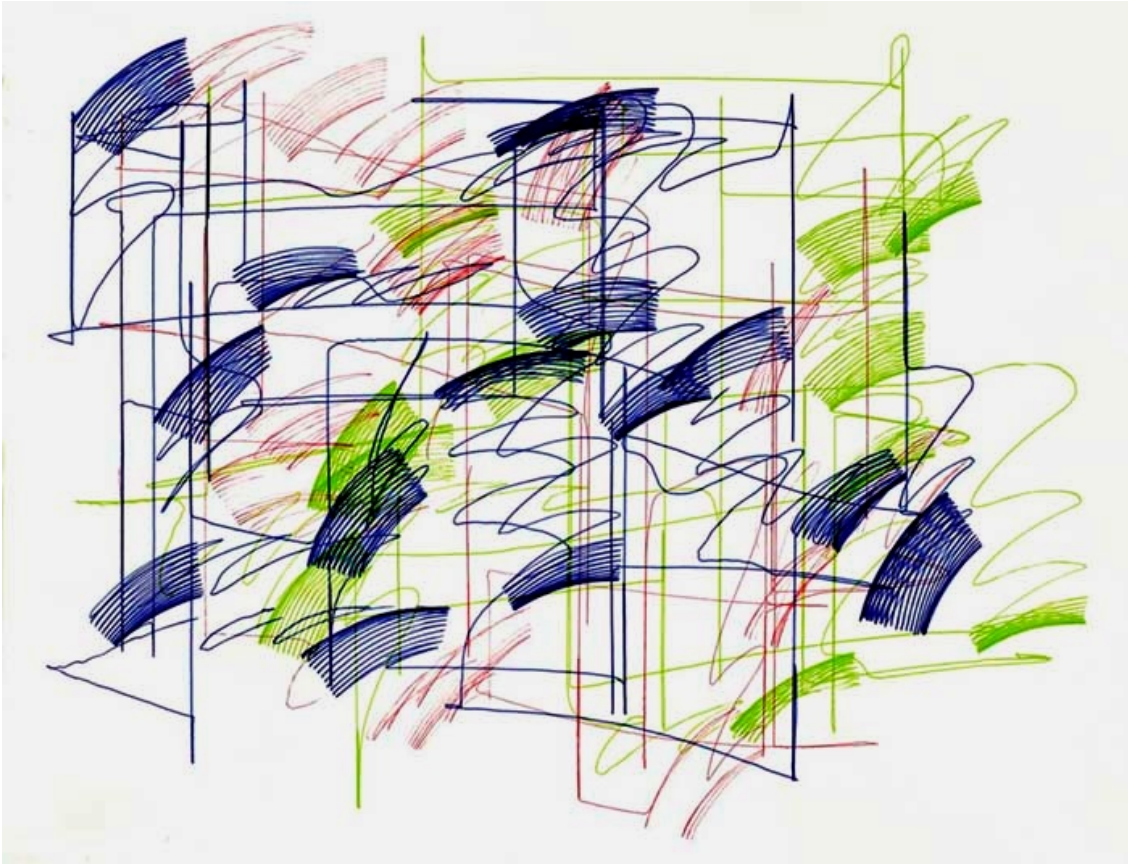
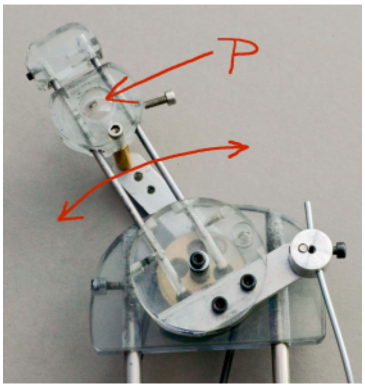
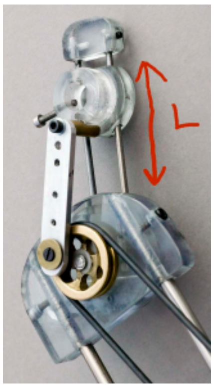


Fig153 demonstrates the facility to change pens at intervals in the drawing. With any machine it is possible to change them to produce a colour original. The pseudo-random nature of the programme ensures that the next colour is unlikely to coincide with the earlier one. Any overlap produces the overprints as in silk screen or lithographic printing.

The separate cross hatch unit

To draw a cross hatch image there are three separate actions to be built. The first is the reciprocating motion of the line, the second is the line progression unit, to make the line shift its position at the end of each stoke; the third movement is to enable these lines to be drawn at different angles. The first is achieved by the straight forward employment of a reciprocating cam. The second, line progression, is done by means of a slow pulley driven cam drive, whilst the third, angle alteration, is achieved by a swinging pivot arm which moves the combination of one and two above. This involved set of interrelated motions may be understood from the photographs below.





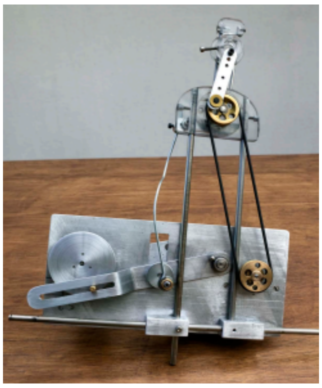


fig154 *fig155* *fig156*

The cross hatching mechanism fig 154 is detachable for the machine to allow fitting of the light unit. Fig155 shows the reciprocating pen arm with the pen at ***P.*** *Fig156 illustrates the cam which moves the line as the pen swings, to ensure progress of the cross hatch.*

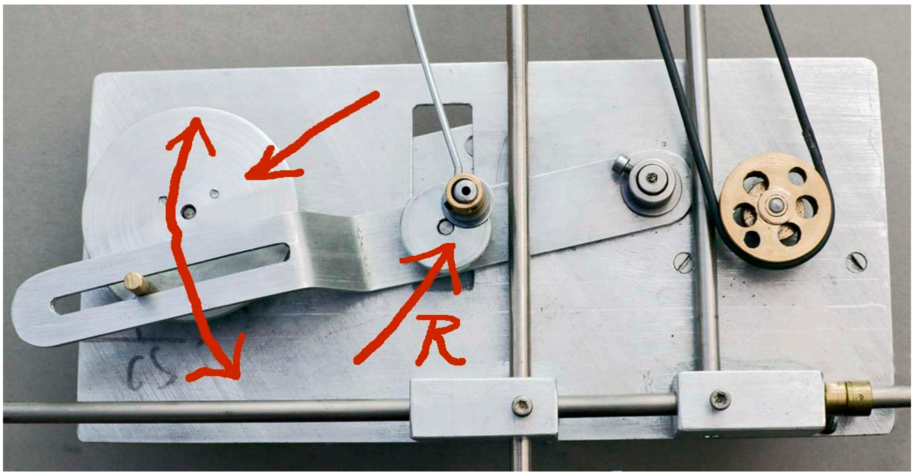


fig157

Fig157 shows the device which alters the slant of the cross hatching. At ***R*** *is the high speed cam which causes the pen unit to swing to and fro making the horizontal lines of the hatching. The pulley on the right drives the line advance moving the slider* ***L****, fig156, to change the position of the line as the pen scribbles.*

This part of machine is seen as a step in the direction of a straight line cross hatching device, more prototype than finished system. It proved that cross hatching was feasible but leaves much room for mechanical improvement.

The revolving light unit

As this machine was able to carry a larger light pen, one was designed to have a rotating wide-slit light box which could accommodate various filter sets. The idea was to exploit the "Go to a co-ordinate and draw something" as with the NSEW when fitted with a rotating pen lift unit. At first the light box mask was modelled on the cross hatching notion as drawn by the 'scribble' pen unit. This was tried and then the range of the masks and filters extended. See images below. At present the latter choice has produced the most interesting results p121. All light pen units are now adapted to be used on a number of different machines.

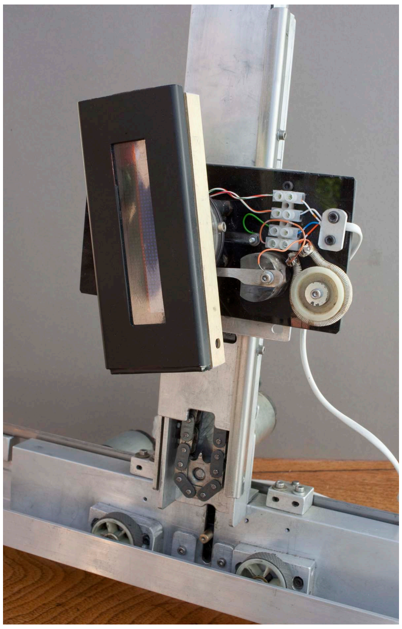


fig158

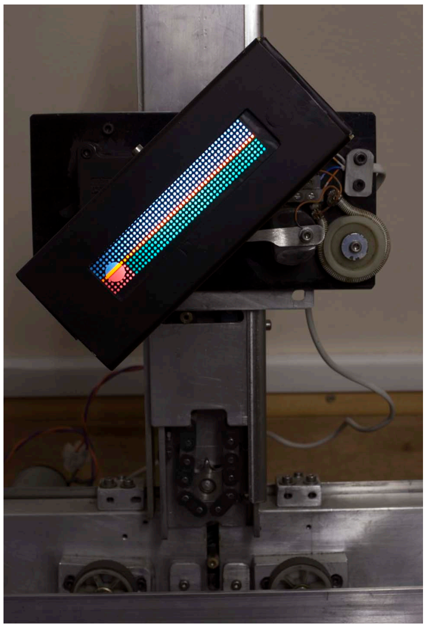


fig159

Fig158; Scribblogram in' light' mode. The light unit revolves and is fitted with an image of coloured gels. This example in fig 159 is a complex light pen where the small pattern of dots with the large disc adds to the richness of the light drawing. See figs160 & 161 below.

The Scribblogram's contribution

Given seven different machines, there is a 'diminishing return' limit to the contribution made by each new addition. The Scribblogram, whilst achieving the basic aims outlined above, does not advance the scope of programmable analogue devices by the same degree that the Sine wave and Turntable added to the range of the Linkogram and NSEW. It is also quite feasible to build a cross-hatching device to operate on the NSEW and Turntable machines. Recent progress, and that in the future, depends more on the sophistication and elegance of the programmers combined with the use of light pens. An obvious direction, which is being planned, is to build a machine dedicated to light only where two moving mirrors replace the mechanical systems.

Selection of images from the Scribblogram

The Images below show the range of drawing and light images produced by this machine. It is planned to redesign the crosshatch effect to make the lines straight and to cause the lines to be at right angles to each other. With the light images, the colour on some was created by a separate colour unit in front of the camera whilst on others the colour was placed on the light unit itself. In this way the range of available effects is increased. Compared with the images from other machines, such as the turntable and NSEW, these images exploit broad brush effects. The light pen is a very large slit image compared with the light pen unit on the turntable.

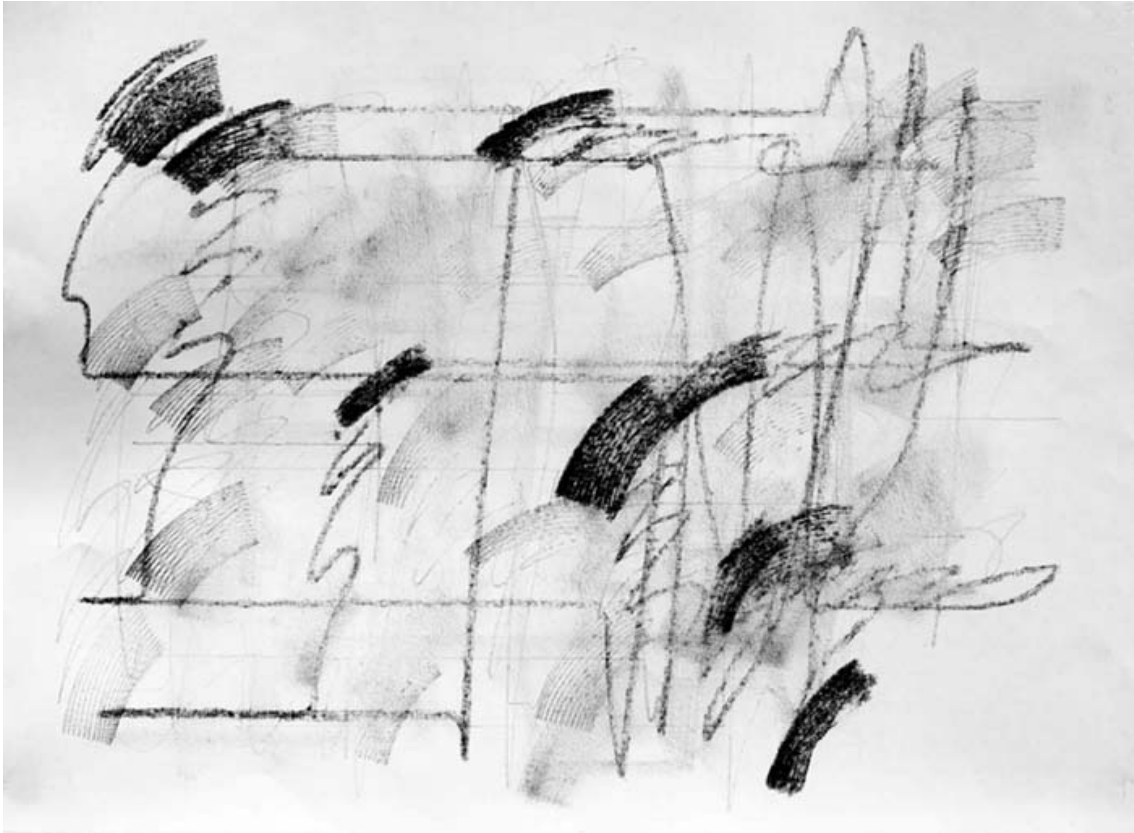


Fig160, if the analogy with hand drawing is taken to a logical conclusion, using charcoal allows the image to acquire smudges. Whilst mimicking hand drawing is not the intent it does extend the range of line character particularly appropriate to a larger machine.

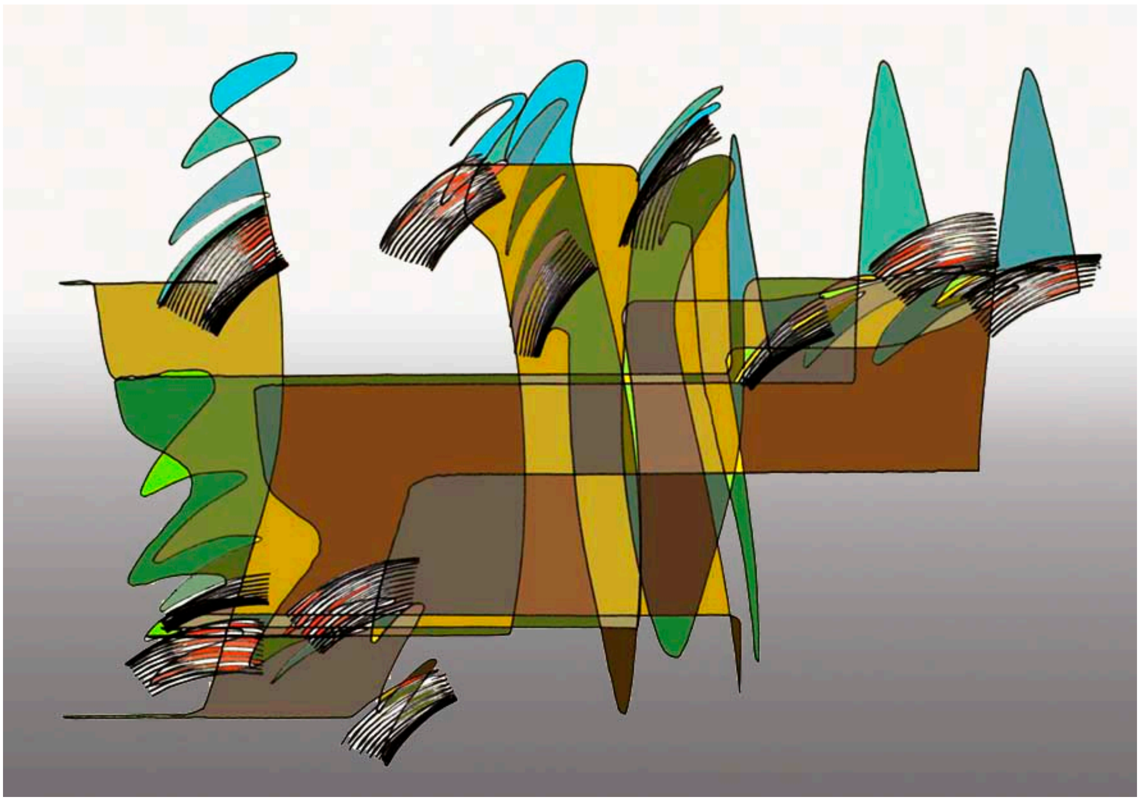


Fig161, an example of after treatment in Photoshop with block colour added to the drawing.

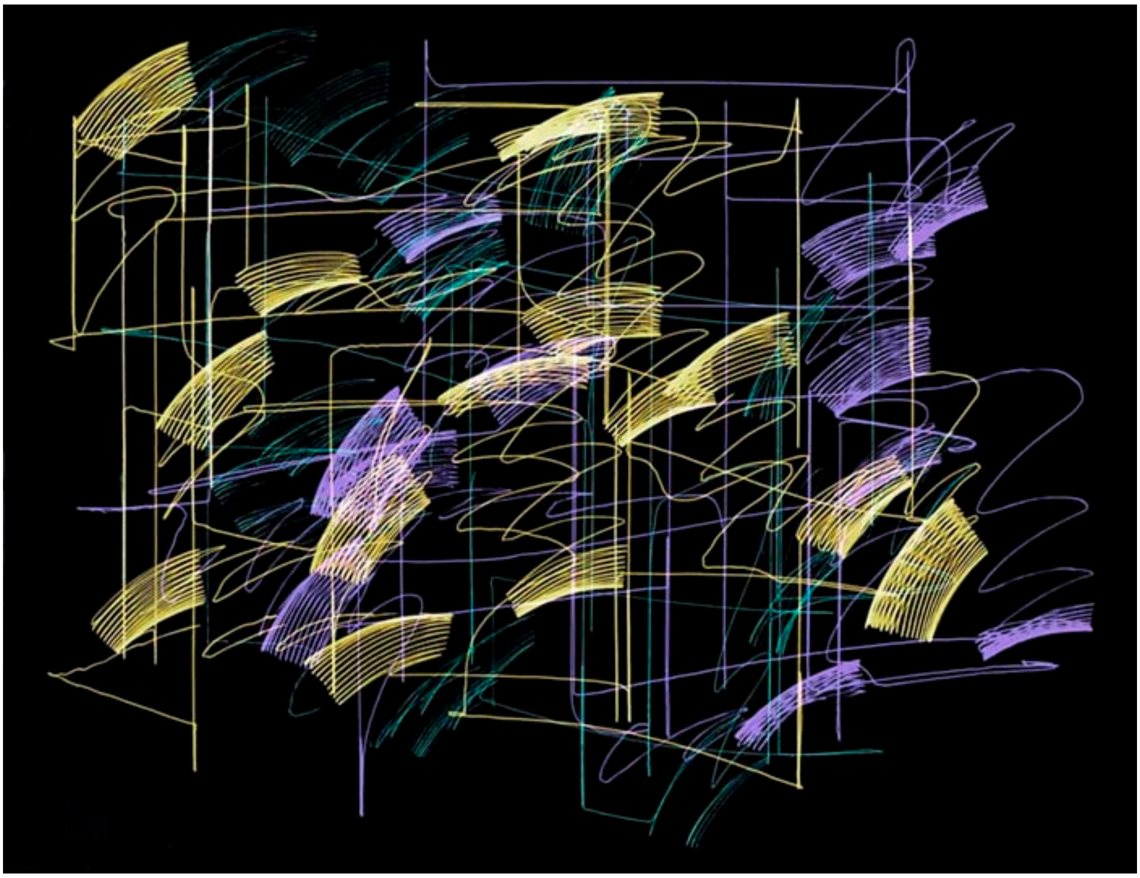


Fig162, is an inversion of the colour and tonality from an earlier drawing.

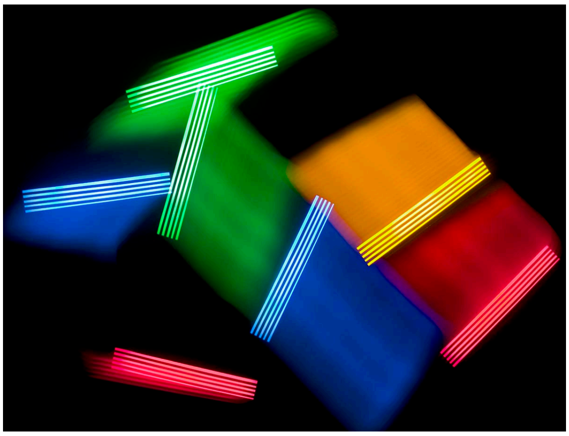


Fig163

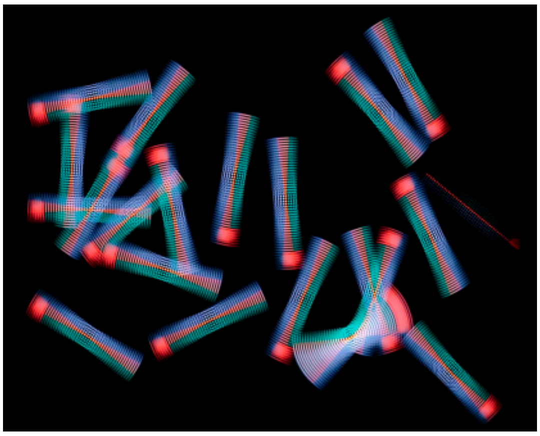
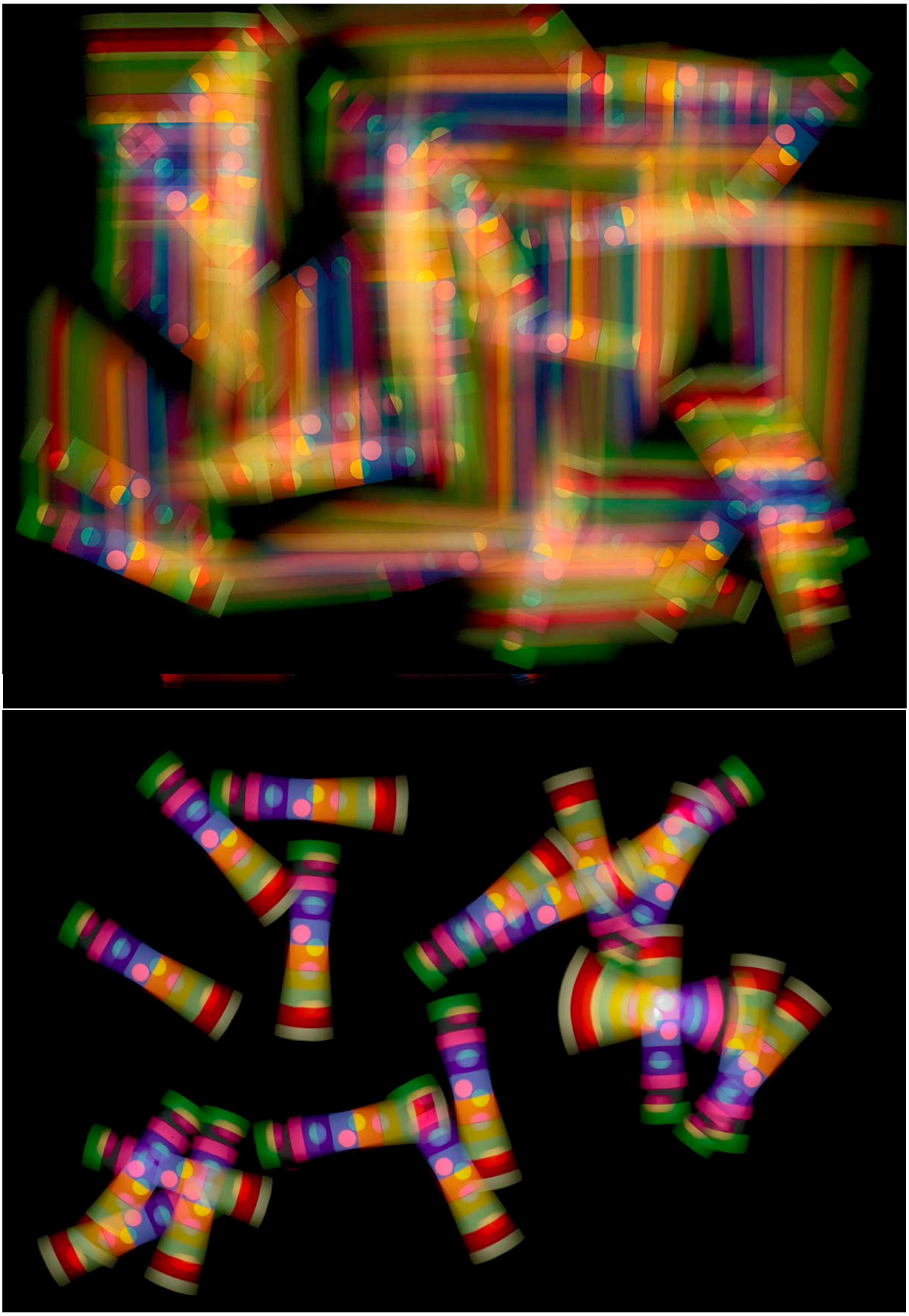


fig164

Fig163 illustrates the 'broad brush' choice where the movement of the 'light brush' is seen in both static and moving mode. In figs164 & 165 the machine was set to allow some of the rotation of the light pen to contribute to the image
fig165.

fig166, shows a continuously moving pen with colour gels on the light unit.



In fig 167 the intention was to create photographic tonality using image movement. The programme sent the pen in 'light off' condition to a co-ordinate; the rotating light was switched on once it had reached its destination. The character comes from the choice of colour gels in the light pen unit. The number of variables is high, governed by the design of the broad brush.

Summary
The variety of drawings shown may demonstrate the advantages offered by the larger size both of plotter and light source. Owing to the vertical stance it is well adapted to use with a light pen and digital camera as well as allowing a different type of graphic image to be explored. A plotter with a robust reliable mechanism is an advantage. Early versions of the NSEW plotters were less reliable until the latest which adopted a similar chain drive to this machine. Reliability makes it has easier to concentrate on programming; helpful if other artists are to use it.

The large slit light pen unit was so successful that it was found possible to use it on other machines in addition to the Scibblogram.

Timer programmers

Introduction
As the research progressed, the relative importance of programming increased. This section concerns the declension of programming as applied to electro-mechanical drawing machines, whose purpose is to make art works. Programmer input from timers is essential to many of my drawing machines and their design and construction is often more complicated than the machines. There are two levels of activity, both constitute programming in the broadest sense. The divisor rests on whether the programming is embodied within the machine or is external to it. The device embodying the programme is referred to as the timer.

Four out of seven machines are externally programmed. These are:- NSEW, NSEWsp, Scribblogram and Turntable. (The Turntable has features which allow it to be programmed internally or externally.) The three that do not are the Meccanograph, Linkogram and Sinewave, have internal programming which is classified as adjustments to rotation speed and gear ratios; instructions to the machine to act in a particular way. This differs from the externally programmed machines in that the instructions are on a higher level, incorporating timed sequences governing sets of motors. This is a significant difference in kind and has become increasing central to the study.

The overall concept

The design of the timers is governed by the concept of the machines, where the drawn line must have the potential to go in any of four directions, usually at each change of timed instruction. Movement in directions at right angles to each other, Cartesian co-ordinates, are referred to as X and Y axes. Hence the nomenclature X-Y plotters in digital computer terms. This idea suggested the name of two of the machines, NSEW, NSEWsp (North,South,East,West). Consistent with this, three out of four machines are designed as X-Y plotters, whilst the fourth has an X axis combined with a turntable. The Scribblogram is just a different X-Y plotter design.

Three parts to external programming with timers

Programme content in the timer may be divided into three parts:-
Forward/reverse unit, ***Time generator***, and usually a separate ***Selector unit.***

It is possible to combine the Time generator and Selector in the same unit depending on the character of the programme required. Recent research established optimum criteria for the timers. Due to their analogue and mechanical nature, it is easier to build trial and error systems than accurate devices which satisfy these criteria. For some years trial and error was adequate, but now the bar has been raised. Research on the testing, analysis and rebuilding was done by making a graphic output machine to measure the time sequences.

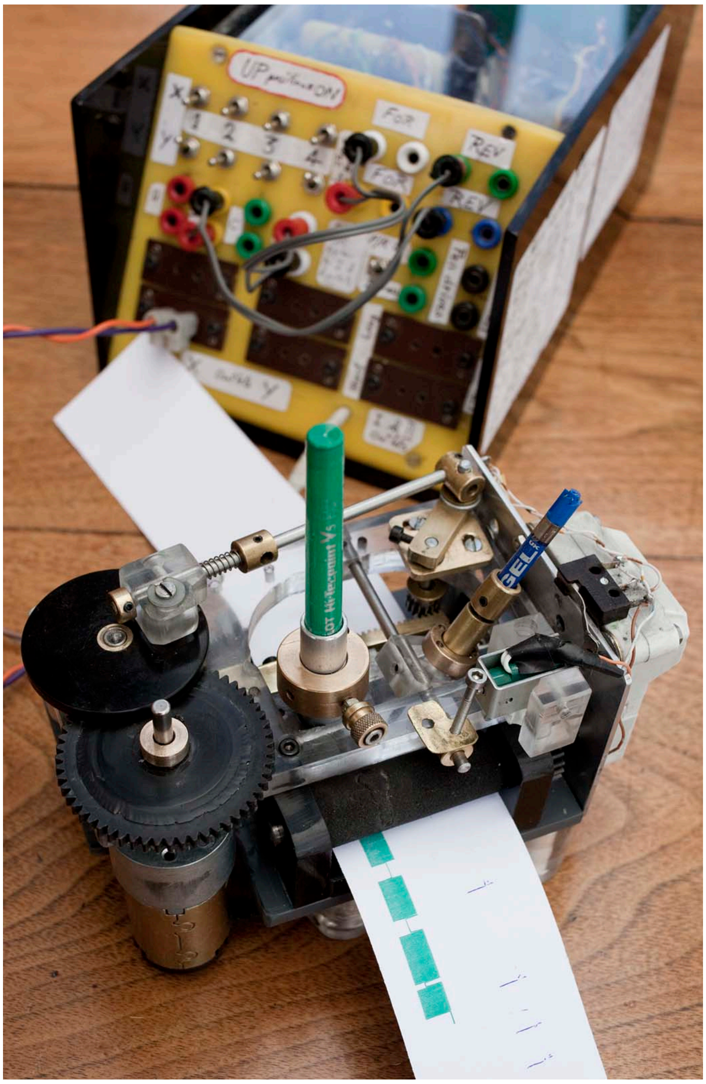
fig 168


fig 168, graphic machine to print the output of each timer, shown hooked up to Timer 1

The programmable machines

Illustrations of the four machines are included here for identification purposes. All the machines share the notion that simple instructions can lead to complexity. With the Meccanograph, Linkogram and Sinewave drawings it comes from mathematical figure generation coupled to devices allowing organic growth of the line progression. In the case of the X:Y plotter based machines, they have no mathematical figures to build on; do nothing other than move in a particular direction. Details of each machine has been given above showing how the design of the machine relates to instructions producing a variety of drawings. While building analogue programmers may be seen as "doing it the hard way" as compared with digital programming, mechanical switching systems are simple, easy to understand and most importantly transparent.

Three essential timer functions

Three main functions and three influential factors have emerged from research. Each carries out a simple task but when combined generates a large number of alternatives. These are outlined and the generation of pseudo-random effects is discussed with the elements which create them.

The timers have three parts with different functions. Each is usually built as a separate unit so that it may be tested in different configurations. Whilst the instructions are very simple, the order in which they are presented to the machine affects the character of the drawing. The functions are listed below:-

1. Forward/Reverse The first is to create a forward/reverse facility (referred to henceforth as 'F/R') to alter the polarity of the D.C. supply to the timer so that the motors may be instructed to change their direction of rotation, often during the course of another instruction. The timing has to be independent of other units and able to run out of phase with them.

2. Time generator. The second is to build a time generator unit to offer a range of times to be programmed. A number of ways of achieving this are outlined.

3. Selector. The third is to make a selector unit to distribute the programmed instructions to two or more outputs. The principal two instructions govern the X & Y motors whilst the third and any additional ones control the pen, light unit or any other action. The machines have differing devices requiring control.

The mathematical basis

The purpose of the timers is to offer a sequence of simple numeric instructions. Where the numeric instruction is a unit of time, (usually seconds), the mathematical basis of the sequence must be addressed. Mathematical sequences are expressed as arithmetic, geometric, logarithmic progressions or series such as the Fibbonacci, but in practice the set's exact nature is influenced if not determined by the characteristics of the components available and then adapted by trial and error. The nature and merits of each are described.

Once the three functions are in place, two other factors, order and speed, have a bearing on the overall programme. The order in which the functions are deployed is crucial and the relative phase relationship governs the character of the programme as well as creating elements of pseudo-randomness. Relative speed at which the three functions are driven is important. Each unit often has its drive motor; relative speeds operate the switches, controlling the duration of the time outputs. Finally the start positions of both the timers and the machines have a big influence on the nature of drawing and its repeatability. Three essential functions and three influencing factors identify six variables which create a large number of alternative configurations. They may be seen as criteria for a working programme.

Variables as criteria for a programmer

a. *The Forward/reverse unit, is usually put first. It changes the polarity to all units but provision is often made to switch it in or out. This increases the range of programming choices as it has such a critical effect of the drawing.*

b. *The time-generator creates time sequences in seconds or fractions of a second. It has proved important to include a separate and out of phase Pen outlet. For example having the X axis on one outlet and the Y on one which is out of phase offers extra programming choices; considerably increasing the variety and richness of the drawings.*

c. *The Selector governs both the order in which the outputs are switched on and the time allocated to each output. This allocated time allows a particular segment of instructions to pass and constitutes the final 'message' to the motors.*

d. *The order of the three units alters the content of the segments of information sent to the motors. Usually the F/R is placed first as this has been found to work better than any other configuration. The relative speed of the F/R also has a bearing on the drawing character and can be responsible in generating gesture like effects.*

e. *The relative speed of each timer unit also influences the final times. This can be subject to individual or overall control by resistors in the circuit. The speed chosen needs to match the speed of the machine motors to govern the optimum length of each line drawn.*

f. *The last variable is concerned with the accuracy to which the start positions of the machines and timers may be set. It is possibly the most difficult to do as the smallest shift in the geographic placing of the time generator and machine linkages has a disproportionate effect of the potential for accurate repeatability. This factor was recognised early on in the development of computer systems by Turing (Turing 1952). It was found that even with the most deterministic system that very slight differences to the start point made disproportionately large changes to the final result. The modern expression for this is termed the "Butterfly wing effect".*

Pseudo-randomness; its causes

Under circumstances where their relative speeds **do not** fall into small whole number ratios, the variables have been found to create a pseudo-random effect. It is employing a sequence which would take a very long time to repeat. This is the case even with the five variables alone. However the pseudo-randomness effect is 'amplified' or enhanced by the mechanical complexity of cams, linkages and gear ratios built into the machines themselves. In particular this applies to sets of gears where the ratios are **not** in simple whole numbers. As the variables increased, much research has been concerned with the ramifications of each small unit, assessing the way in which it contributes to the final drawing. Designing a repeatable system has compounded the problems of navigating a route through a potential minefield of variables. Throughout the design process there has been a tendency to engineer in too many variations, with the result that it is very difficult to comprehend the route through the variables when compiling a programme. Simplicity has only been achieved by a process of rebuilding and removing any element seen to be surplus or irrelevant. The pursuit of simplicity following initially complex solutions is typical of design process.

The timer/programmers vis a vis machine characteristics

The effectiveness of a timer is tested when drawings are being evaluated. The principal question is whether the timer's programme or the machine's characteristics has the most influence on the drawing. For instance Timer 3, driven by three printed circuit 'flip flop' devices is the most limited and least satisfactory of all four timers and struggles to interact well with the machines. In the case of the NSEWsp machine its sun and planet gearing characteristics exert such a strong influence as to override the input from any programme and 'family likenesses' are apparent.

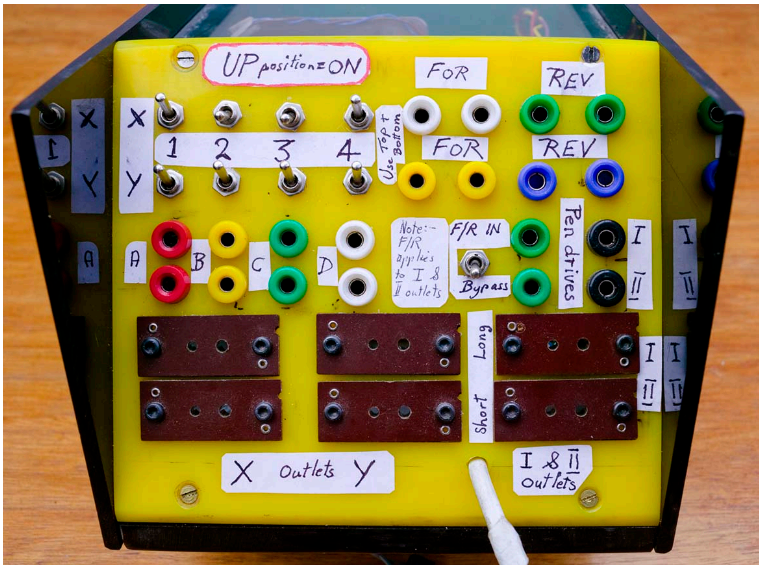
This is also the case with the Scribblogram (cross hatching) and to a certain extent with the Turntable machine (where a circular input is strong). Clearly this is a continuum with instances at the opposite end where a programme from Timer 4, a very complex device, will be able to exert a noticeable imprint. To establish this with any degree of certainty could almost justify a separate study but is nonetheless an intriguing question. With multi-pen set ups and in light machines, where coloured gels are arranged in the light pen, these cases tend to dominate the image and often outweigh the input from the timer.

Given that these variables also combine with pseudo-random input this becomes a very complex issue not lending itself to clear cut divisions.

Four different timers, in many versions, have been built to date, each offering a slightly different approach to sequencing. The main differences are outlined in this section where the design of them has a bearing on the conceptual issues.

There are four Timers T1,T2,T3 & T4. The aim in all was to create a balance between a deterministic set of simple instructions and a controlled amount of pseudo-randomness. Early timers were built with only two outlets for the X and Y axes but as the research progressed, more outlets were needed to accommodate the increased scope of the machines. The deterministic versus random ratio is crucial; various systems have been tried to offer ease of programming and generate a large number of sequences. In recent designs the timers are built to complement the characteristics of the machines, as their characteristics have a significant bearing on the way instructions are converted into a drawn line. For example type of motion, harmonic or linear was discussed above on pg 56.

Timer 1

fig169 

In fig169 the full range of programming controls can be seen.

Timer 1 was the first separate unit, built in 2005 around twin ganged 24 point rotary wiper units. The 24 points are divided into sets, the number of points in each set varied by switches. The four sets of X Y instructions were separated at four intervals by one contact point designed to prevent any motor overrun effects, which would have created a radius at each change of direction. These four 'spare' contact points were used to operate the Forward/reverse latch relay and is hooked up by floating leads called 'wander plugs'. The variables offered to the programming of the overall sequence proved helpful in practice although it runs contrary to recent criteria analysis in that the F/R is neither separate nor placed first in the operational order of the units which make up the timer.

Coupled with the main rotary contacts is a secondary set of micro-switches which run out of phase with the speed of the main rotor drive. This particular feature has proved to be most significant, particularly when a rotating pen unit is used in conjunction with the X and Y motion. This timer has been the most successful in many respects although this came about by chance. It has been successful in practice serving as a benchmark for other designs.

The mix of determinism, created by the rotational sequence, and the integral F/R switching is balanced by the secondary out of phase micro-switched outlets. These add a small element of pseudo-randomness to the programme, particularly when the drawing machine linkage character and the choice of start point is taken into account. This underlines the importance of the symbiotic relationship of the machine and timer. In the recent extensive research into the design of timers and machines this interdependence has assumed the most significance. This may be apparent in the appearance of the latest Timer 2 Mk lV and the NSEWch Mk Vll.

Timer 2 Mk lV

Timer 2 has undergone four attempts to extend and vary the scope of Timer 1, two of them within the course of this study. The first two, Mk I and II, were unsuccessful due to insufficient range of variables in and Mk III was too complex. Timer 2 MkIV benefited from experience designing the fully programmable Timer 4. It was kept simple; the varied outputs of the time generator accessed by floating spade connectors and employing two separate drive motors for different parts of the time generator, each subject to speed control. This latter addition was very useful in extending the range.

Timer 2

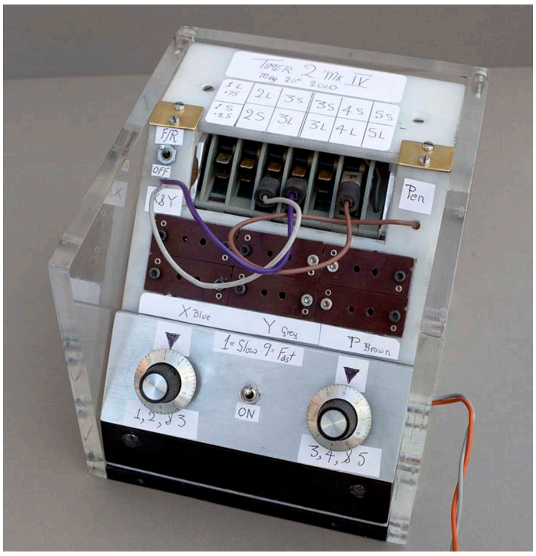


fig170

In fig190 the 'wander lead at the top can be placed in any of 12 positions to programme the timer. The twelve choices together with the variable speeds offer a large number of variables.
The Forward/reverse switch can be seen at the top left hand corner, which when in circuit affects all the outputs. The addition of a separate Pen outlet has proved very useful; earlier designs did not have this facility.

Timer 3

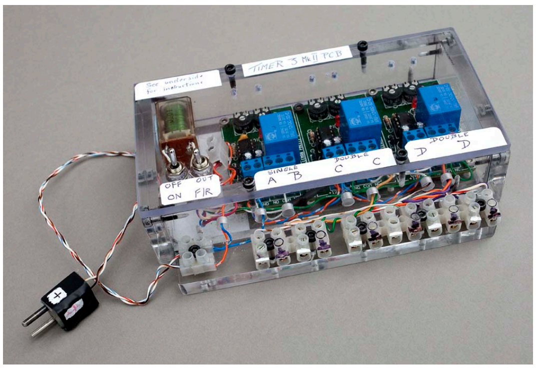


fig171

In Mk II, fig191, the three PCBs are encased in Perspex, the outlets are outside. Screwdriver adjustment access exists for the onboard potentiometers to alter the 'on/off' rate of change.

Timer 3

Timer 3 was an attempt to use 'flip flop' printed circuit boards driving relays to control the on and off of the X,Y and Pen. The idea of three interacting boards, one for F/R and two for outlets A,B and CC/DD (X,Y and Pen actions may be linked to any outlet combination) is simple as well as being small. It offers the simplest programme possible and augments the greater complexity in timers 1, 2 and 4. The disadvantage is the limited range of time outlets. Off the shelf PCB boards tend to have a small range of adjustments. The same outcome would have been achieved with a motor controlled cam and micro switch set up; PCBs are just smaller.

To go any further along the route of electronic control would be getting into a hybrid arena mixing digital and analogue controls. The PCB system charges a condenser through a resistor which then triggers a state change and operates a relay. It works in the same way as a motorised cam driven micro switch. These PCBs are not subject to external digital control and act in a sufficiently 'analogue' manner to justify their use. It is the least satisfactory of all four timers and its inclusion is academic to increase the range of timer exploration. In this form it cannot compete with the more versatile timers T1,T2 and T4; to do so would have meant employing digitally programmable chips in a more sophisticated circuit design.

Timer 4

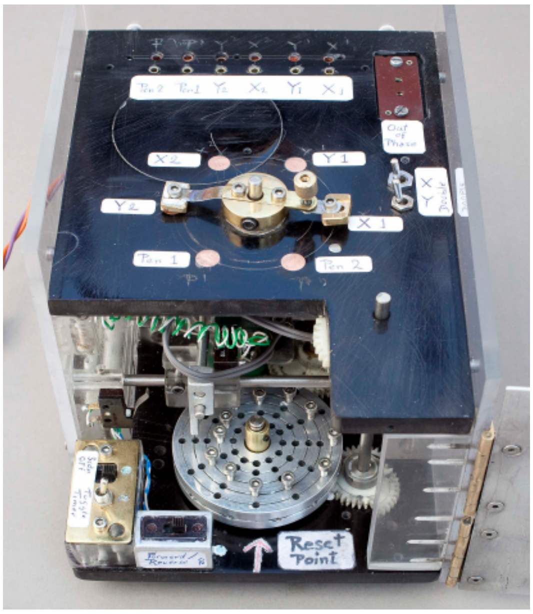


fig172

Fig192 shows the programming disc and pins which allow different times to be set. The distributor is in the middle with the outlets to the motors at the top. The important forward/reverse 'in/out' switch is on the lower left. The brass switches are for resetting only. On the top right is the 'out of phase' Pen outlet; an essential attribute for a wide programme range.

Timer 4 was the latest attempt to approach a facility readily available in a digital programme. A sequence of twelve numbers is available. The programming is by placing pins in twelve sets of five holes drilled in a circular disc. The timer 'reads' the time information according to the distance of the pin from the centre and then the circular disc moves into the next reading position for the next instruction. The pin nearer the centre gives the longest time and vice versa. This scheme differs from all the other timers; it is 'digital' in idea, albeit in a limited form, having variable pin placing. The time information gathered, by the 'reader' arm, is transmitted to the X,Y or Pen outlets by a rotary distributor. Whilst this timer is fully programmable in theory and proves that an analogue version can be made, it is not yet certain whether it justifies its construction. It was complicated and difficult to engineer to reach a standard of reliability and precision and it does not necessarily surpass simpler timers in making significant additions to the range of drawings. *(Timer 4 was designed specifically for this study and is compared with earlier timers which have had longer use)*

However its presence extends the range of programmed output and helps in questions regarding the predominance of timer or machine. During the study, pursuing this range extension, Timer 2 was redesigned twice, Timer 3 once and Timer 4 created from scratch with one modification.

Assessment of programming

The criteria above are met by the four timers. The potential number of drawings is so large that only a relatively small proportion is likely to be made, however examination of some permutations is sufficient to show the extensive variety of machine and programmer combinations. Analogies exist with conventional printmaking where the balance between deterministic and random effects is a significant part of the process. The whole drawing operation is a design discipline, not a random ***'press a button and see what happens'*** activity. Following a path and making changes in making machine drawings is analogous both to hand drawing and computer art, where images are repeated and modified until a satisfactory outcome is achieved. Analogue programming research in this study provides a platform to examine the balance between determinism and pseudo-randomness owing to a repeatable process with easy access. All aspects of mechanical operation may be watched as they occur. This is a significant divisor between analogue and digital computer based work.

Footnote:- *From literature searches, regarding programming in past and current analogue drawing machines, other practitioners have found their own way to control their machines. Examples are Ihnatowitcz (Zivanovic, 2005), Nicolas Schoffer,(Schoffer,1956) and John Whitney, (Moritz 1997). These artists worked as sculptors and film makers; using timers to programme drawings machines is perhaps less common.*

Light pens and colour changers

IS THIS A PHOTOGRAPH?

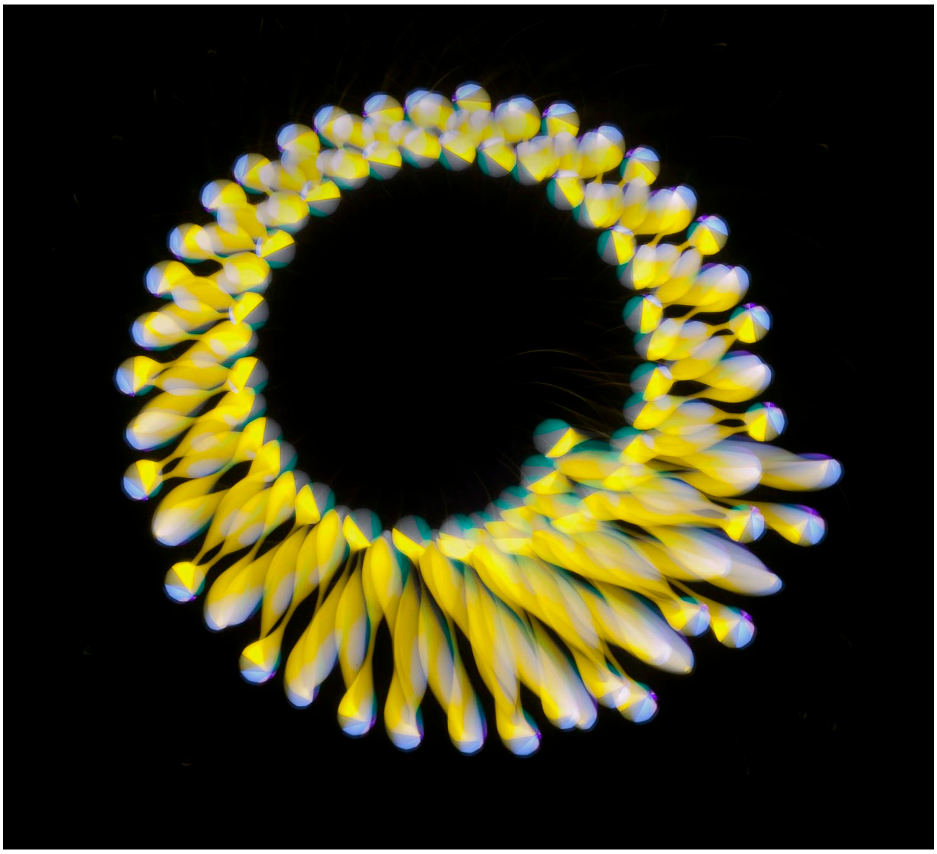


fig143

Fig143 is a turntable light pen image where the colour and size of the light source was in a constant state of flux. This, and other similar images, encapsulate the notion of a tonal colour image where the result may be 'read' in the same way as a conventional photograph.

Light pen rationale, reinventing photography?

Having a photographic background, the idea of drawing with light was present from the outset. John Whitney (Moritz,1997) did this in his filming in the 50's using his WW2 bombsight computer. 'Photography' of course means 'Drawing with light'. If a machine created light image resembles a conventional photograph then is it possible to propose a 'reinvention of photography'? This is relevant once perception becomes a component of the evaluation process. It is another factor when the implications of machine art work are debated in the context of art practice.

Using an enlarger as a light source in a darkroom, it is relatively easy to employ even crude mechanical movements of the light sensitive material to generate monochrome and colour drawings. Adding a shutter in the light path increases versatility. Early research brought together movement, shutters and photographic paper generating three dimensional effects

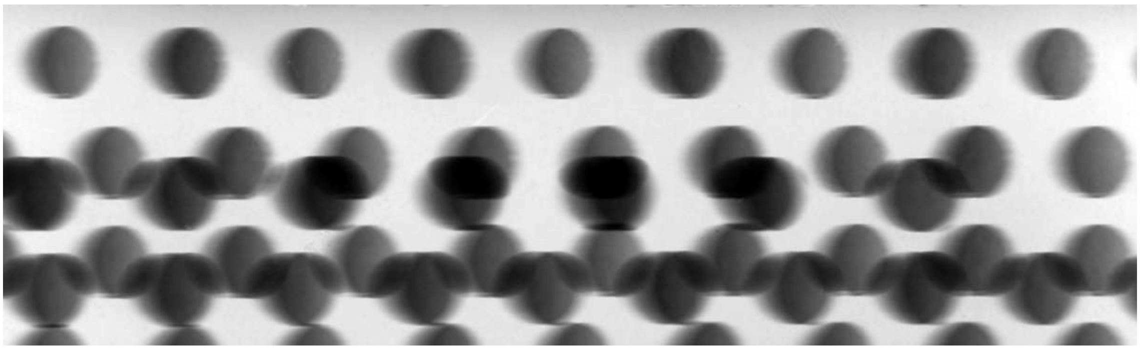
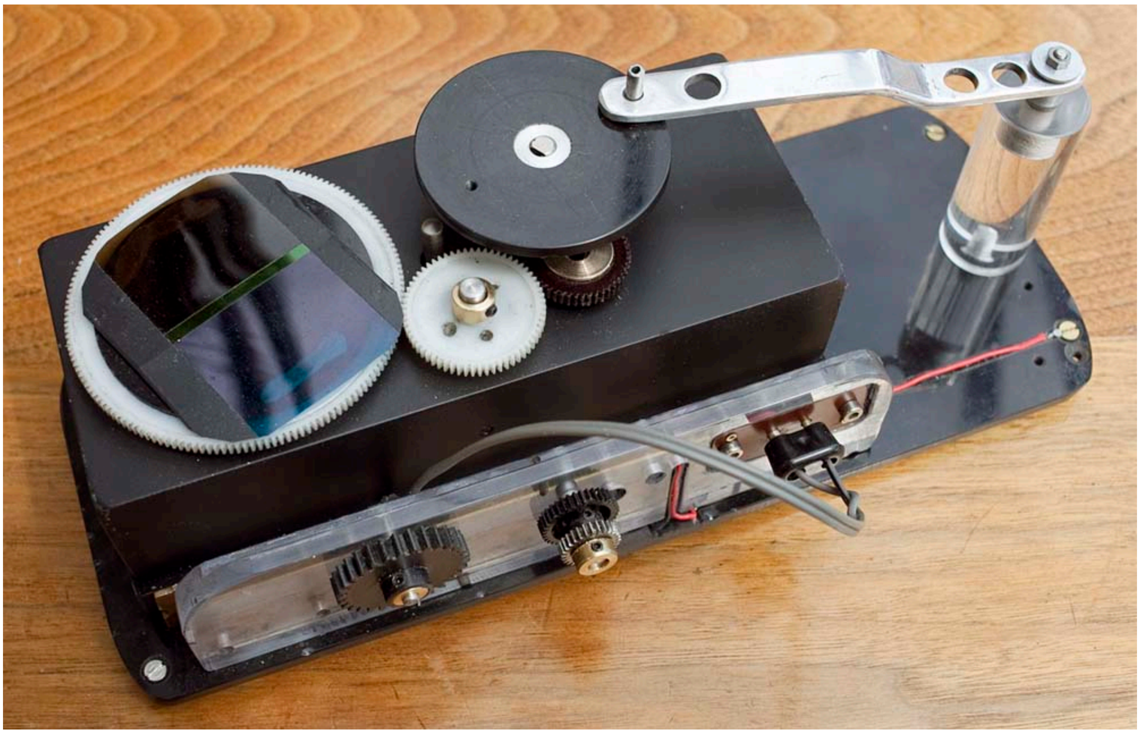


fig173

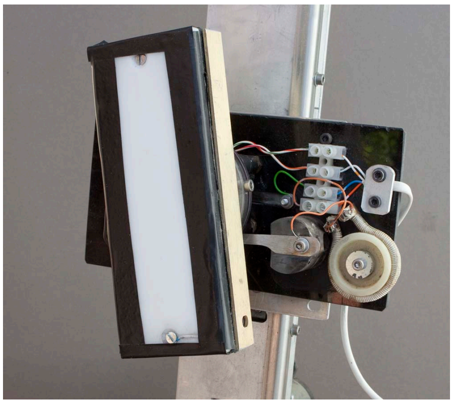
The feathering action of a louvre type shutter in the path of a projected disc image, created soft edges; quasi-shadows. The result could be ‘read’ as a photograph. Cast shadows are the means by which photography represents solids. This eye/brain response motivated the research raising questions of perception.

Light pen units

More sophisticated and precise mechanisms were made with more variety and control, exploiting the facility to change pen colour during the drawing. Increasing complexity affected design and colour changing methods. Initiatives grew, leading to the present devices described below.



In fig91 above the light pen unit sits on the turntable machine and moves across the radius as the turntable revolves. The workings are housed, containing gears to vary speeds of the revolving slit image and the colour gel rotator. The black rectangular box on the left is moved by the cam and linkage on the right. It is detachable, compact and versatile. It can replace the large light unit on the Scribblogram and is usable on four out of the seven machines. In place of gels on the light unit colour can be introduced by gels on a rotating shutter at the camera position.



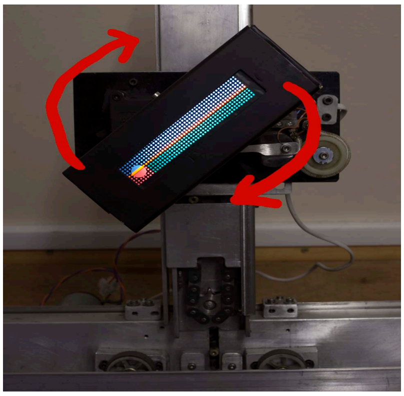


fig 158 *fig 159* *Figs158 and 159 are close ups of* the light pen unit sen earlier in the Scribblogram section.

Future developments

Drawing with light has reached a point where it is likely to become the major choice for most images. The high level professional digital camera has influenced the direction of the research and professional practice. Much work has been done adapting the machines to accommodate light pens. The next machine is to be in light mode only. Earlier experience with bi-refringence promises pure spectral light. Modern sensors accommodate an increasing gamut of colour although it will be some time before the intense blues make their way to print due to the limitations of pigments. Electronic LCD displays can take advantage of the extraordinary colour range of screens. Given future pre-occupations with light in still or moving form, the remit of this study is with the still image. It is able to generate an almost infinite variety of image; time-based images are the topic of other studies. It is intriguing to speculate how past artists might have responded to the idea of a brush where colour and pattern can easily be altered on the move. This would have been and still is the stuff of dreams.

fig174

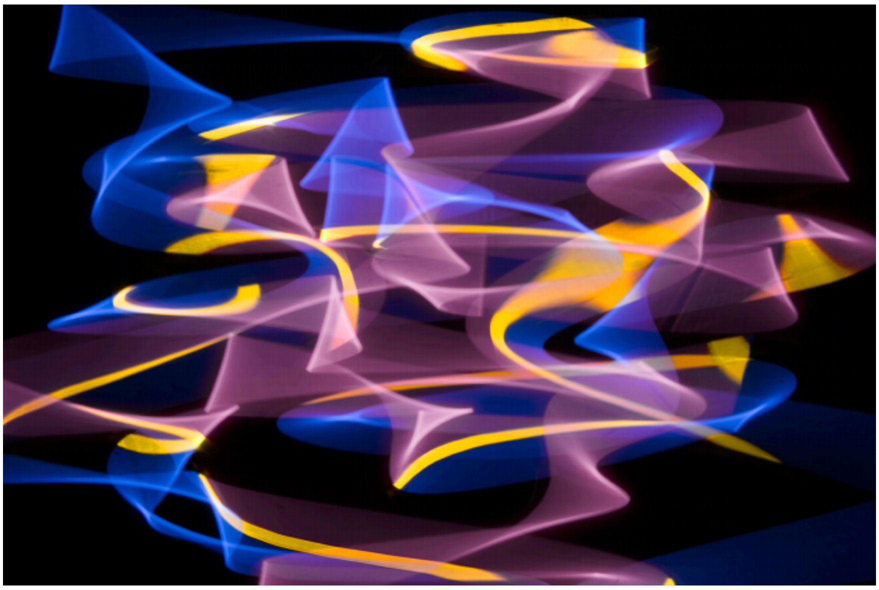



Fig174 an NSEW light drawing with a fixed colour wedge over the rotating light slit.

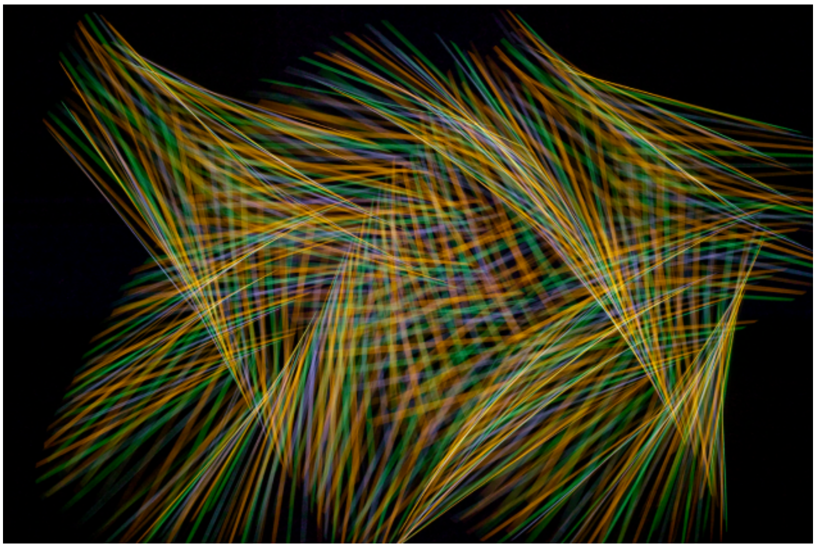
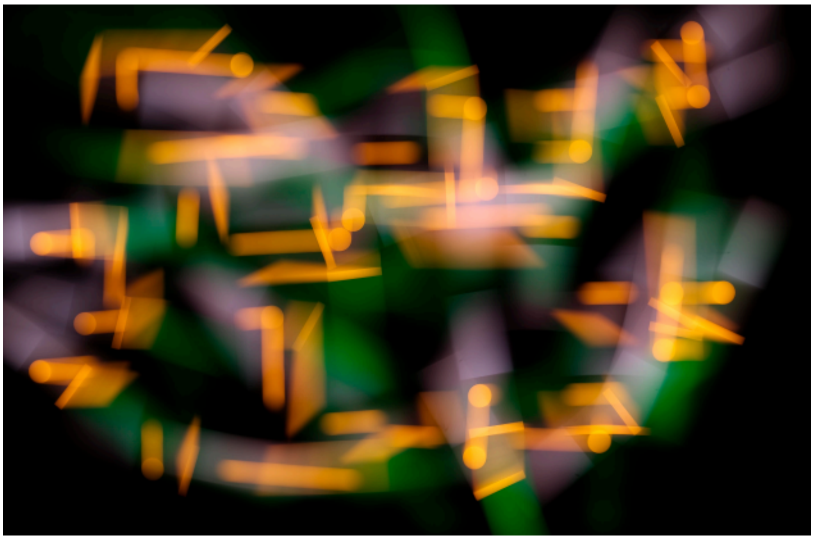
fig175

Turntable image in fig175 using a large thin slit light source with colour gels on the shutter.

fig176

Multiple colour spot light source,NSEWch and Timer 1. See aloso multi pen graphic versions pg67

fig177 

Large slit-light source in fig177 on NSEWch with Timer 1. as was used on the Scribblogram.

After-treatment & colour

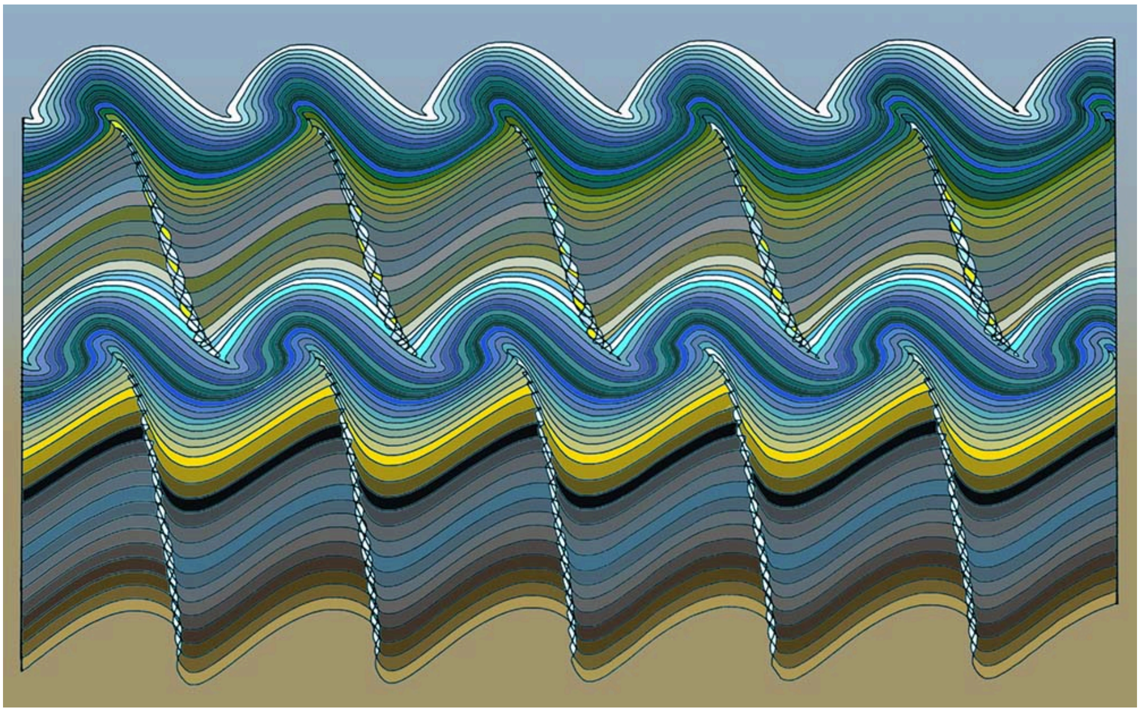


Fig 129, shown earlier is a labour intensive application of colour to a Sine wave drawing. The intention here was to emphasise the wave character. The wave-break effect was very difficult to achieve in the original engineering of the machine; it is felt the colour enhances this feature.

Career precedents

Throughout my career colour has been a major concern. As a printmaker I classify myself as a colourist. Early modernist influences were Kandinsky, Braque, Cezanne, Klee, Moholy-Nagy and Mondrian, (Kandinsky,2006),(Bauhaus,1968), (Klee,1948-1979),(Rothenstein,1957), (Stoichita,1979). They influenced my approach to colour photography. This facility enabled me to pay my way through art college in my third year where my work was bought by advertising. A Kodak scholarship in 1964 in the USA was to study colour photography and at Manchester I obtained an M.Phil. in colour measurement. Colour led my printmaking in silkscreen, lithography and etching and appeared in Beyond Photography (Tait,1977)

Early machines were as preoccupied with colour and light as with graphic output. When the graphic results were developed to a high standard of line and content it was a natural step to add colour. Adobe Photoshop allows linear drawings to be processed as colour prints. The computer and printer combination replaces the lithographic press. The thinking is the same. My professional practice rests on the use of colour.

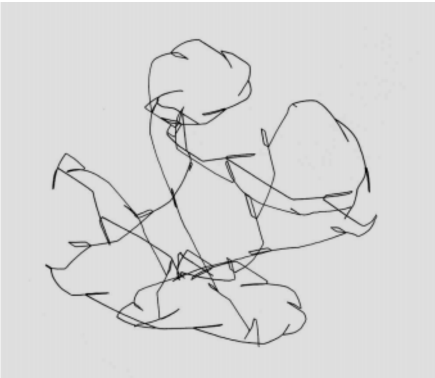


fig102 original

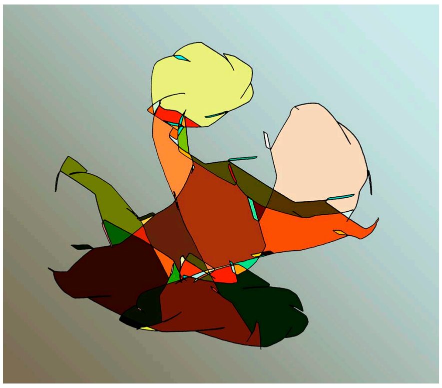


fig102

Figs102 original & 102 show the 'before & after' states. The drawing was one of the first to display a gesture-like quality to the line, it is hoped that the colour enhances this characteristic.

Two stages

Where the output of the drawing machine is graphic as opposed to light, the images are made in two stages. First the drawing is made by analogue means ; the next stage involves digital treatment. The drawing is scanned and further production takes place in Adobe Photoshop.

Drawings originating in line satisfy the original intent to explore numeric sequences generating complex drawings. At this stage the condition has been met. Following my printmaking practice I feel that adding colour enhances the intrinsic qualities of the drawing. In stained glass design, linear images are spaces filled with colour and is the established method. Photoshop follows this precedent.

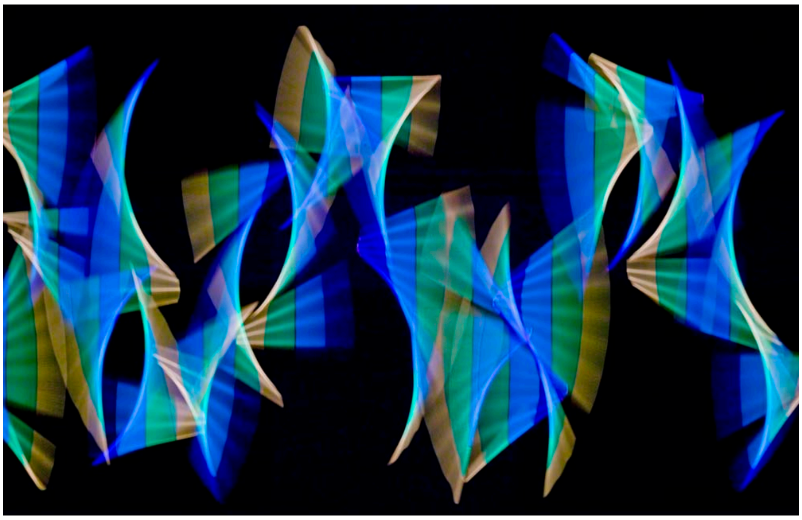
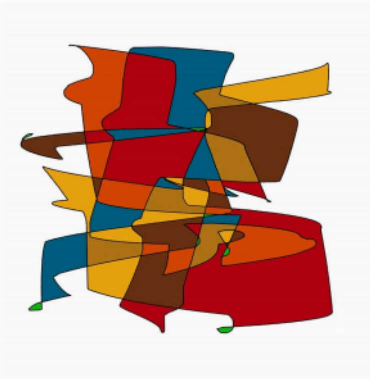


fig178

Fig178 is a rotating slit light image with a fixed colour wedge on an early NSEW machine.

When drawing with light, the process starts with a 'colour pen'. Tone and colour are recorded simultaneously by the digital camera. Afterwork consists in Photoshop refinement, occasionally in inverting the tonality and colour to give an image on a white as opposed to black ground.



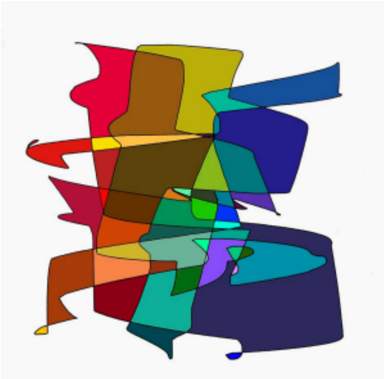


fig179 *fig180*

The two drawings in figs 179 and 180 demonstrate different approaches to colour addition. The theme of the top left image was desert colours; small edge shapes denoting green shoots. The top right colour scheme followed a 'constructivist rule base' inspired by the spectrum.

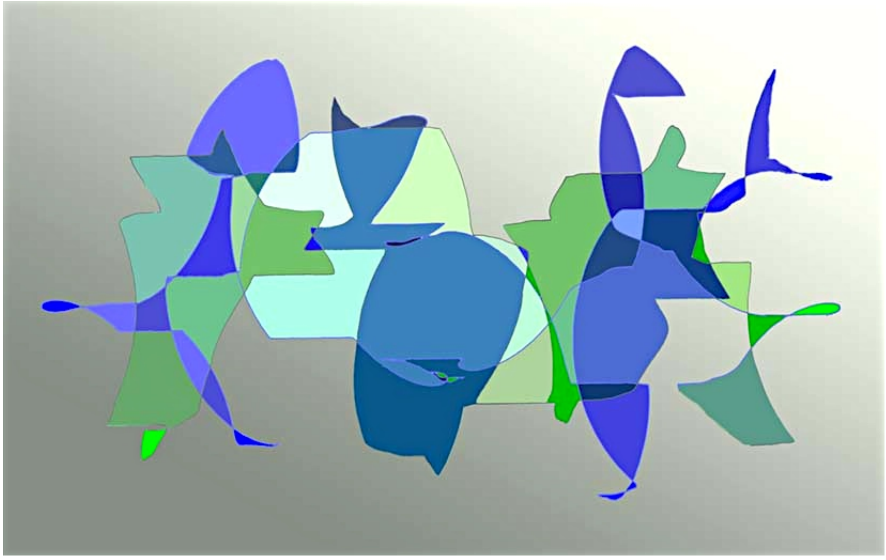


fig181

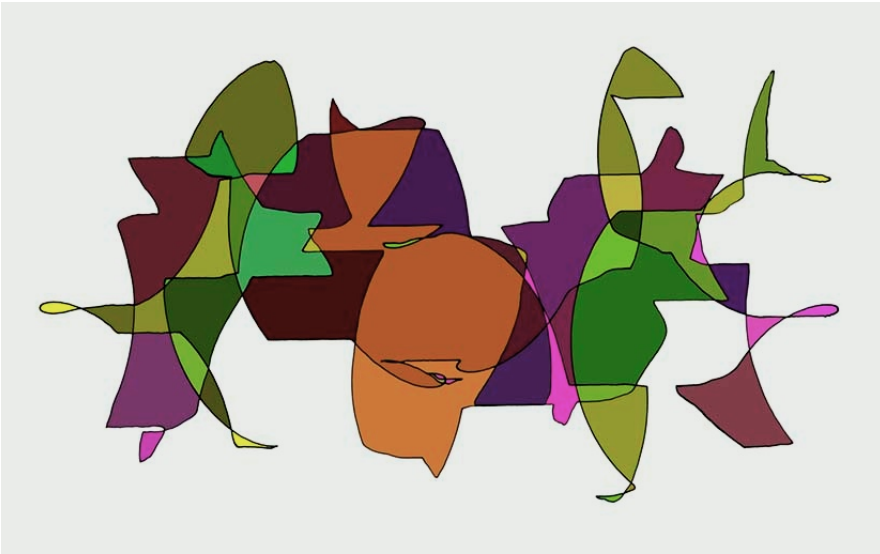


fig182

Fig182 exploits the dynamic feel of the shapes in contrast to the quieter rhythm of fig181

Adding colour to the graphic output

Photoshop provides the means to select any enclosed spaces in the drawing and if required to add a colour or graduated ground. The decision method is wholly intuitive and often led by a constructivist approach (see fig204 p136). The drawing often suggests a scheme and may be carried out on a numerical basis. Colours in the computer are numbered from 0-255 in RGB so increments can follow a mathematical pattern. Colour may also be introduced by RGB characteristic curve manipulation in Photoshop. See Linkogram fig90 p65.

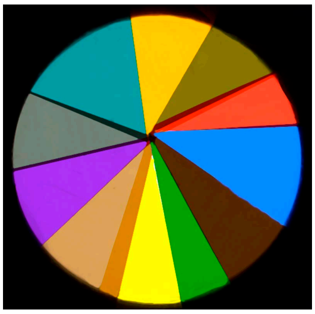


fig183

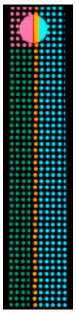


fig184

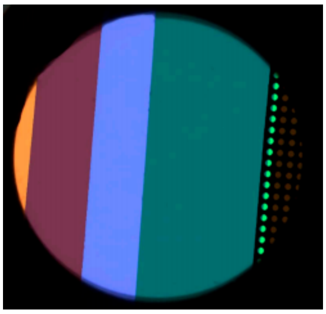


fig185

In figs 183-185 three colour wedges are shown, not to scale; the vertical one is much larger than the circles. Colour gels do not need to be precise as they are usually in constant motion.

Choosing colour for the light pen

The light sources on each light pen unit are provided with holders to accept coloured gels. The colours chosen may be left static, overlaying the basic shape of the pen or caused to change as the drawing unfolds. Whilst the choice of coloured gels is similarly intuitive in the graphic method, there is provision to modify them for brightness and saturation during afterwork.

fig107

The movement of the light slit in fig107 (also on pg 66) has given some feeling of three dimensional quality; the image perhaps takes on some characteristics of a photograph.

Aesthetic aims using light

The overall aim when drawing with a light pen is to create tonality and colour to be 'read' in the same way as a conventional photograph. It is hoped in some cases that the eye and brain might treat the images as being 'photographs' of an object. If this were to be the case then interesting questions may arise concerning art process. This is debated in other sections.

Why colour is important

I have tried to explain how and why colour is used and identify its role in decision making. A subsidiary outcome to this may allow some speculation on art process, with particular reference to its effect on the viewer. Colour is an essential part of my work, albeit secondary to studying simple numeric sequences generating complexity. The choice of colour is often influenced by a constructivist rule-based approach. It plays a supporting role in presenting the outcome of the numeric sequences but the significance varies with the manner of its use and the intuitive reaction to the drawing's characteristics.

In graphic mode, colour is a post-production decision, not subject to programming, apart from constructivist notions. With light, available colour choice is a pre-programming decision, unlike line direction, which is subject to the machine characteristics and the programme. However once selected, colour becomes subject to the numeric sequence, contributing in the same way as a gear ratio or linkage characteristic to the final image. Light drawing can be monochromatic relying on tonality alone, but usually colour increases the impact drawn from the machine and programme combination.

When the images are exhibits, it is felt that the colour serves to draw in the viewer
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proposed ... on of an
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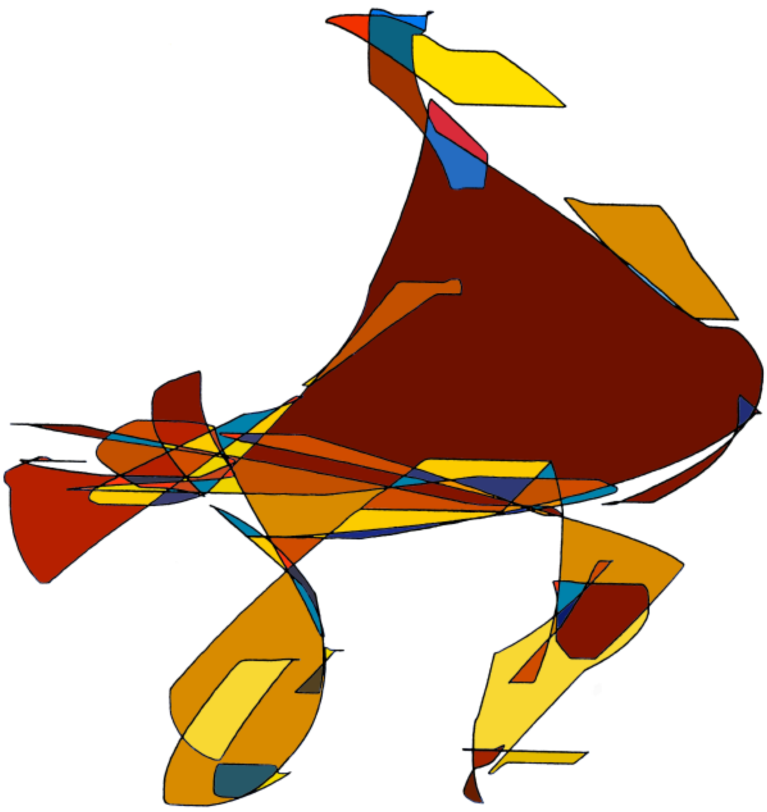

Conclusi...

I have tri... nown the
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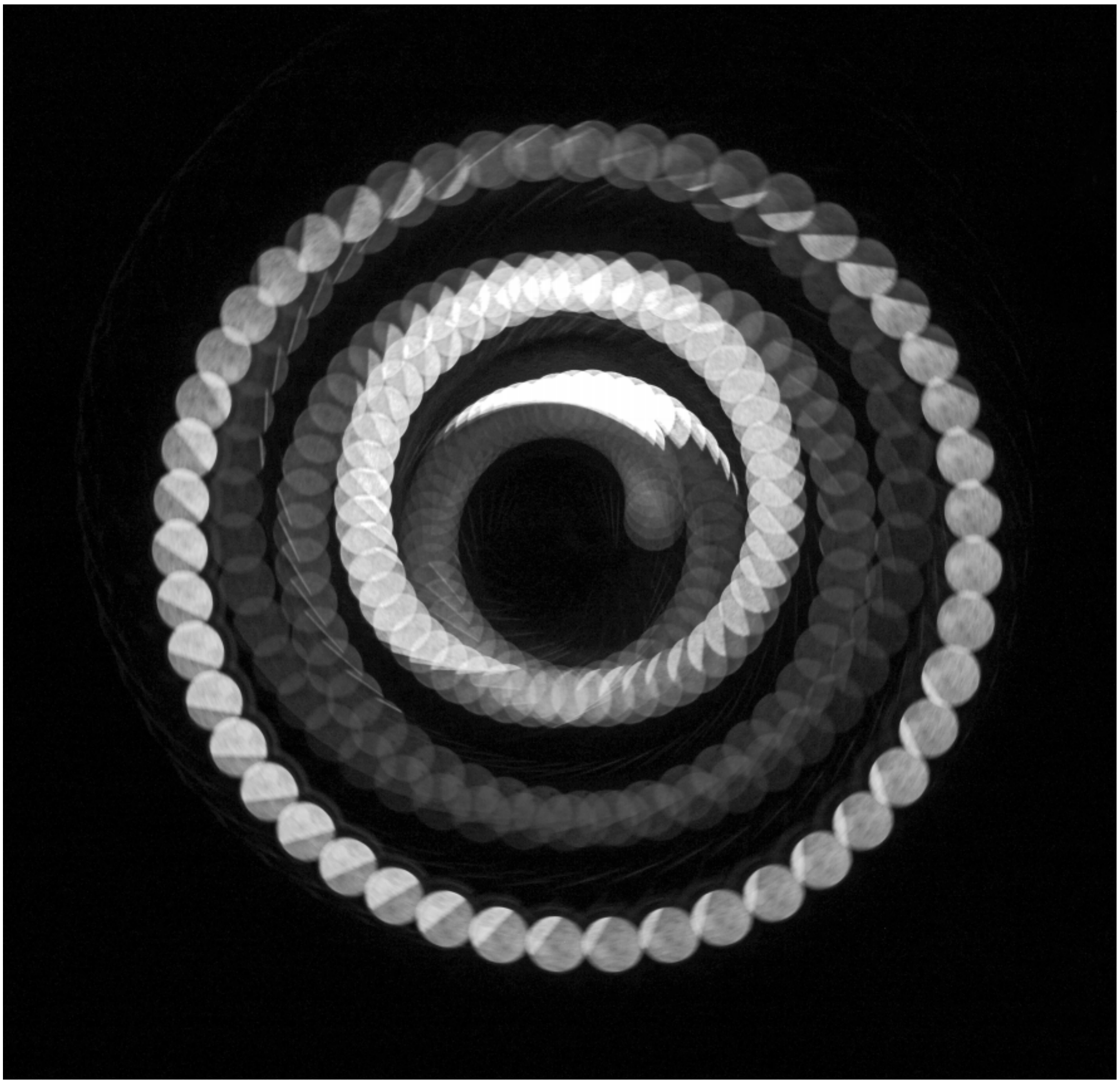
and con... as raised
questions... gible and
transpare... and these
are addre... cal detail

and an historical survey from this book. The Bibliography is complete and those interested in further study can use these references.



fig

Drawing with light

The end

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GLOSSARY OF TERMS

Note: *Many words below are in common usage but may be used in a specific way relating to the machines and are qualified accordingly.*

Algorithm Set of instructions with no exceptions. An algorithm is a programme but the converse does not necessarily apply

Amplitude Extent of movement of a cam or crank. Interconnected aspects, Frequency and Phase relating to decaying harmonic motion
Analogue Operations by variation of quantities. Non digital machines
Axis The direction of travel of a particular part of the machine. See also Cartesian coordinates
Art process Occurrences in making art
Auto reverse Switched direction of a motor
Backlash Amount of play in a mechanical system; tends to spoil line quality
Bas relief Offset superimposition of a negative and positive image giving three dimensional appearance
Ball-race Precision bearing, reducing friction and increasing precision
Cam Rotating cylinder with irregular profile producing harmonic motion. 'Cam' is also used to denote a 'crank' throughout the text (my idiosyncrasy)
Camera rig Holds camera above machine
Camera cradle Sets camera on machine
Cartesian coordinates Location of a point in space in terms of its distance from a set of axes, X,Y or Z
Carriage return Reversing pen or table direction at the end of its travel
Chain drive Creates linear motion with automatic carriage return
Chaos Unpredictable behaviour of a system not appearing to have a rationale
Concept Abstract idea
Criteria Standards by which something can be judged, usually in list form in this text and applies to decision making
Decision Judgement reached, selected from alternatives previously generated
Design process Steps in problem solving
Determinism Events consequent on antecedent causes. Opposite to random
Discrete Consisting of separate parts
Digital Discrete signals representing data in numbers. Digital computer
Evaluation Assess the worth or meaning of.
Fulcrum Pivot, about which a lever turns
Frequency Rate of movement recurrence. Interconnected aspects Amplitude and Phase relating to decaying harmonic motion
Gear box Casing containing a set of gears
Gear train Sequence of gears, usually alters the overall ratio
Gear ratio Numerical relationship of gears i.e 10 to 40 teeth = 1:4
Gel Transparent coloured plastic sheets used in light pens
Graphic Relates to pen or pencil usage, as opposed to light
Harmonic movement Reciprocating or Sine wave motion
Harmonograph Pendulum driven drawing machine
Intent Aim, purpose, design
IMP (See also SEP) **I**ntegral **M**echanical **P**rogramming
Inter line spacing Distance between two drawn lines, aimed to be ~2-3 lines wide for optimum aesthetic effect
Judder Abnormal vibration spoiling line quality, see also Backlash
Kinetic Caused by motion

Latch relay Electro-magnetic switch which holds its position once activated.
LED light source Light Emitting Diode
Linear motion Output proportional to input giving a constant speed of travel as opposed to the variable speed of a cam drive
Line quality Smoothness of a line's form and edges. Absence of ripple or judder
Light pen Specific light source shape used in place of a graphic pen/pencil
Lyssajous figures Shapes produced by the intersection of two sinusoidal curves, axes at right angles to each other
Linkage Interconnecting levers/rods transmitting motion to a mechanism
Louvre shutter Revolving flat plate/s between lens/film governing exposure
Mathematical figures Shapes determined by mathematical principles
Meccano Construction set of metal parts
Method Practical actions involved in carrying out Intent. See Evaluation
Micro switch Miniature switch unit, usually activated by contact arm or lever
Movement types Linear, non linear, circular
Multi pen Pen unit with up to five pens
NSEW Compass point notion where a point can be programmed to move in any one of four directions at any time
NSEWch abr.- **N**orth,**S**outh,**E**ast,**W**est machine with **ch**ain carriage return drive
NSEWsp abr.- **N**orth,**S**outh,**E**ast,**W**est machine with **s**un & **p**lanet drive system
Out of synchronization Movements not in unison. See also Out of phase
Out of phase Two motions out of step with each other. Incremental phase change can create organic line progression. See phase
Organic growth Having characteristic of living plants or animals. Drawing grows incrementally over time
Phase Positional relationship of two harmonic movements. Interconnected aspects, Amplitude and Frequency relating to decaying harmonic motion
Photoshop Adobe image manipulation computer software
Pen lift Device lifting pen off the paper
Platen Surface on which drawing is made
Potentiometer Variable resistance with three terminals. One side increases its resistance as the other diminishes
Programme A sequence of instructions leading to an outcome. Can combine determinism and random elements. Timed sequences, settings of gear ratios, or relative motions speeds. Programmes are not necessarily algorithms
Pseudo-random Any instruction sequence unlikely to repeat in a short time span. Contrasts with deterministic aspects
Random Mathematical number sequence creates uncertain values; chance occurences
Ratio Relationship of one number to another i.e. 1:4. Also applies to gears
Relay Automatic solenoid operated switch device. See also Latch relay
Ripple Unwanted line characteristic, lacking smoothness caused by judder and backlash
Rotary wiper Rotating arm making electrical contact with a number of radial points. Acts as a sequential timer switch, the basis of Timer 1
Rotating pen unit Radial graphic pen. Supplements and enhances X:Y motion in plotter rigs. See also Multi pen

Rotating slit light unit Narrow light source able to revolve. Used on Timer controlled X:Y plotter based machines
Sequential timer Machine to generate a sequence of electrical timed pulses to drive motors, see also Timer
SEP (see also IMP) **S**equential **E**xternal **P**rogramming
Sinewave Graphic depiction of harmonic motion as a mathematical curve
Sinusoidal Having the characteristics of a sine curve
Shutter Device for allowing a timed pulse of light to reach a photosensitive surface, see also Louvre shutter
Slit light A very narrow light source, basis of most light pens, and often rotated. See rotating slit-light unit
Sun & planet mechanism Set of gear wheels, where a radial gear revolves around a central gear. Basis of drives in NSEWsp and Turntable machines
Synchronization Two motions remaining in step with each other. Relates to :- Linkogram, Meccanograph, Turntable and NSEWsp machines
Third party response Evaluating a drawing 'As if it had been made by another person'
Timer Device generating sequence of timed electrical pulses to control motors and move parts of a drawing machine. See also Sequential timer
Turntable Revolving drawing platen
Wave Sinusoidal shape generated by main part of Sinewave Machine
Wavebreak An abrupt platen direction reverse, interrupting the smooth path of the wave shape in the Sinewave machine
X axis The horizontal, side to side movement of the drawing platen or pen. First Cartesian coordinate
Y axis The vertical, up and down movement of the drawing platen or pen. Second Cartesian coordinate
X:Y ratio Crucial relationship which influences shapes drawn. Operates in conjunction with linkages and timer programmes to create drawing's character