MDI

CNC serendipity

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James Edward Bennett

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How can designers contrast the uniformity of CNC machining with the serendipitous nature of creativity?

ABSTRACT

This thesis discusses the traditional use of (computer numerically controlled) CNC machining and the role of a designer to control the manipulation of (computer aided manufacturing) CAM software, CNC data and materials. The engaged designer has the capability to add qualities of digital tectonics onto a specified form through the process of working intimately with a CNC lathe. They experiment using abstract forms to find unique qualities that come from the cutting action of the tooling in a lathe. The designer takes on the role of the self-learner to become competent in the software, technology to apply complex textures and expressions.

The designer can capitalise on unforeseen events, adds the action of craft to this industrial production method, creates beauty and provokes an emotional connection. Understanding the potential in the design possibility is to accept the serendipitous influences that can be controlled and the inevitable moments that cannot.

The core of this research is to show how a designer claims authorship of their design at the making stage. They can define the margin of control and randomness, whether something has become too serendipitous, compromising the crafted form, or remained banal, repeating the precision machining, and releasing any character from the object. By finding the best design solution and replicating the same understanding a craftsperson has of their traditional tools. The designer observes, analyses, succeeds and fails, recognising the potential of their experimentation. Using Cross's model of exploration, generation, evaluation and communication there is the strategy to see the unexpected, realise the potential and make it desirable. Learning the ability to manipulate digital surfaces and identify serendipitous qualities produced by the physical fingerprint of the machining process.

Opposing the machines' engineering, expressing the marks of the tool on an object, the imprints behaving as fingerprints left on a surface, is a unique characteristic. Something that makes the end user want to experience, feel, move and use it every day. These surprising results may influence the future of how design is conducted with digital technologies and adding digital complexities inspired by traditional craft to design more interesting artefacts.

CHAPTERS

1

introduction

—1—

INTRODUCTION

This research seeks to create 'design knowledge' through exploration and iterative processes. It examines the traditional use of CNC (Computer Numerically Controlled) machines and will investigate tooling surface qualities through design and serendipity testing the limits of the CNC lathe.

The use of the word 'serendipity' refers to the fact of making a fortunate discovery by accident, the 'aha' moment when your experiences deliver a new solution. The idea of letting go of total control of the machine, loosening the leash, relates to a statement by David Pye "the failure of mass production is not that it is incapable of producing quality products, but that it has created a system of undifferentiated, uniform and characterless products; a material culture which gives little value to workmanship and craft, and the potential of both" (Pye, 1968). In the decades since he wrote this our roles as designers have evolved significantly as we understand the aesthetic and functional implications of emerging technologies that give us a new perspective of craft.

Digital technologies use digital data to reproduce on a mass production scale, creating a monotonous routine and a precise, smooth finish. A small change in the data or a physical difference in the process allows the production of individual objects. Digital tools now make it possible for designers to access processes traditionally controlled by the engineer. These extra skills to a designers' arsenal helps to install qualities of diversity that are always apparent in human crafted objects expressing personality onto an object. The digital craft occurs through the innovative use of the machine leaving a surface texture ingrained on a design, a digital imprint unique to the mode of making.

"The failure of mass production is not that it is incapable of producing quality products, but that it has created a system of undifferentiated, uniform and characterless products; a material culture which gives little value to workmanship and craft, and the potential of both" - Pye, 1968.

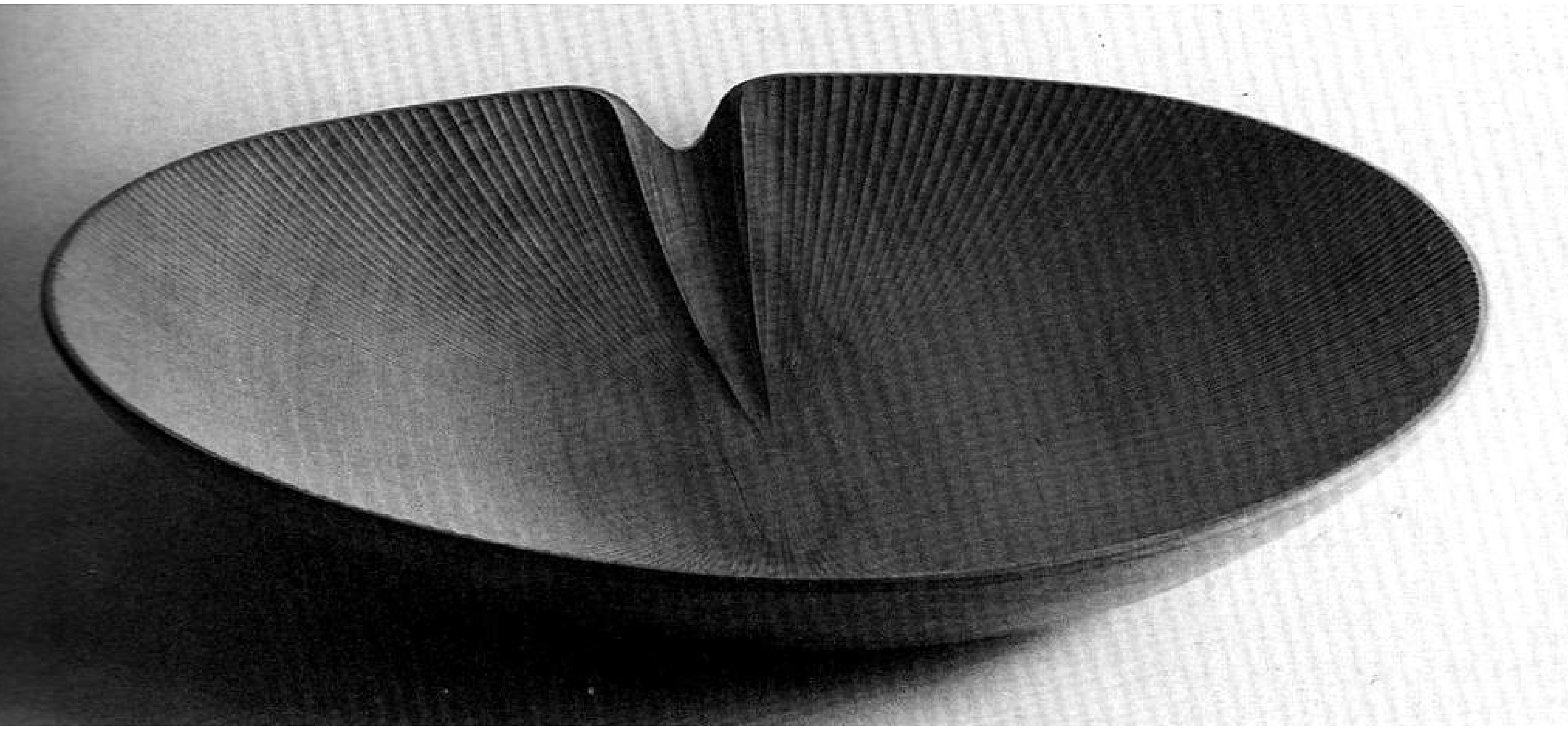

fig1. David Pye's Wild Service Tree Dish

2

terminology

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TERMINOLOGY

SERENDIPITY

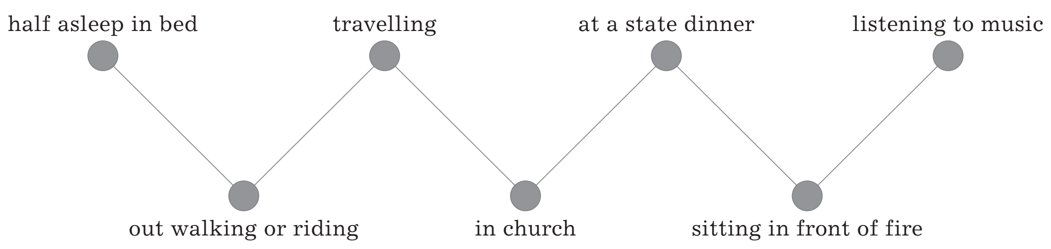
Ser-en-dip-i-ty

1. *The faculty of making fortunate discoveries by accident.*
2. *The fact or occurrence of such discoveries.*
3. *An instance of making such a discovery.*

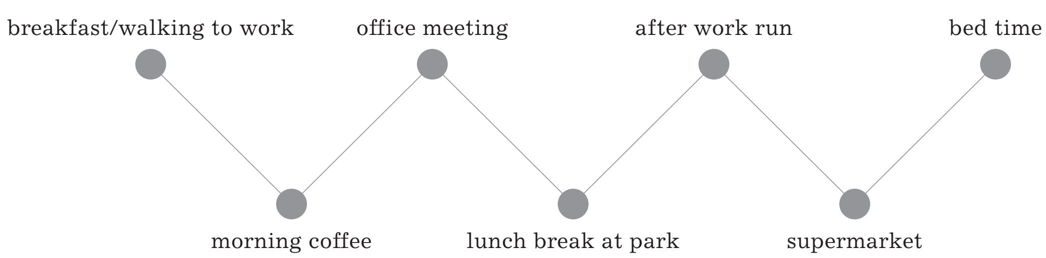
Serendipitous ideas occur all the time but are quite often spirred on in unlikely meetings or events. These meetings or events result in insights offering new opportunities and new ideas, for a designer these moments occur from sleeping to waking up, performing the usual routines to the process of making. Any point of the day can provide a spark to an idea, from an interaction with another person, an activity or during relaxation. In relation to my process the serendipitous idea can occur in interactions with the (computer-aided design) CAD software, G-code and machine, physical manipulation offering differing results. My role as the designer is to control the maximum potential of tactile and aesthetic value produced at the finish.

“The notion of ‘designing for serendipity’ is an oxymoron because once we try to ‘engineer’ it into a system, users may no longer perceive the experience as serendipitous, Designers shouldn’t try to offer serendipity on a plate. Instead they should design tools that create opportunities to have experiences they might perceive as serendipitous” - Dr Stephann Makri

"Upper Class"



"Business"



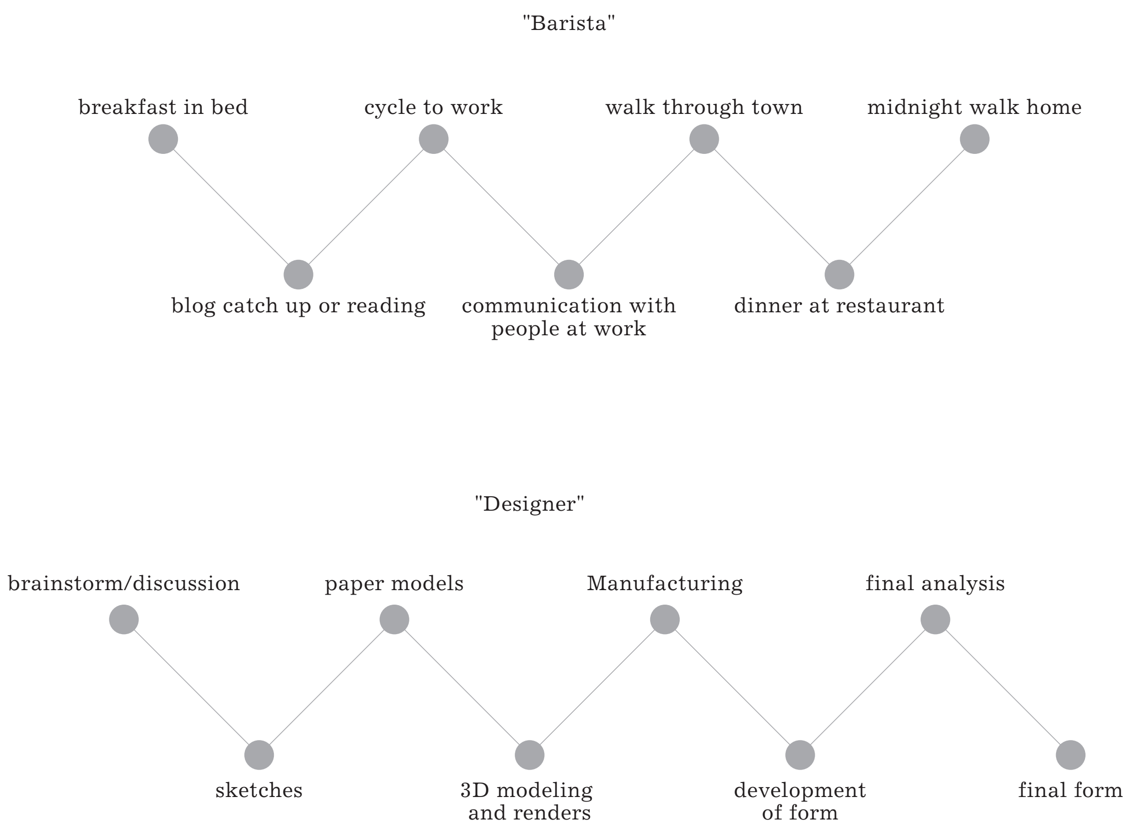


fig2. Chance moments everyday

“The secret of inventiveness is to fill the mind and the imagination with the context of the problem and then relax and think of something else for a change” - Glegg

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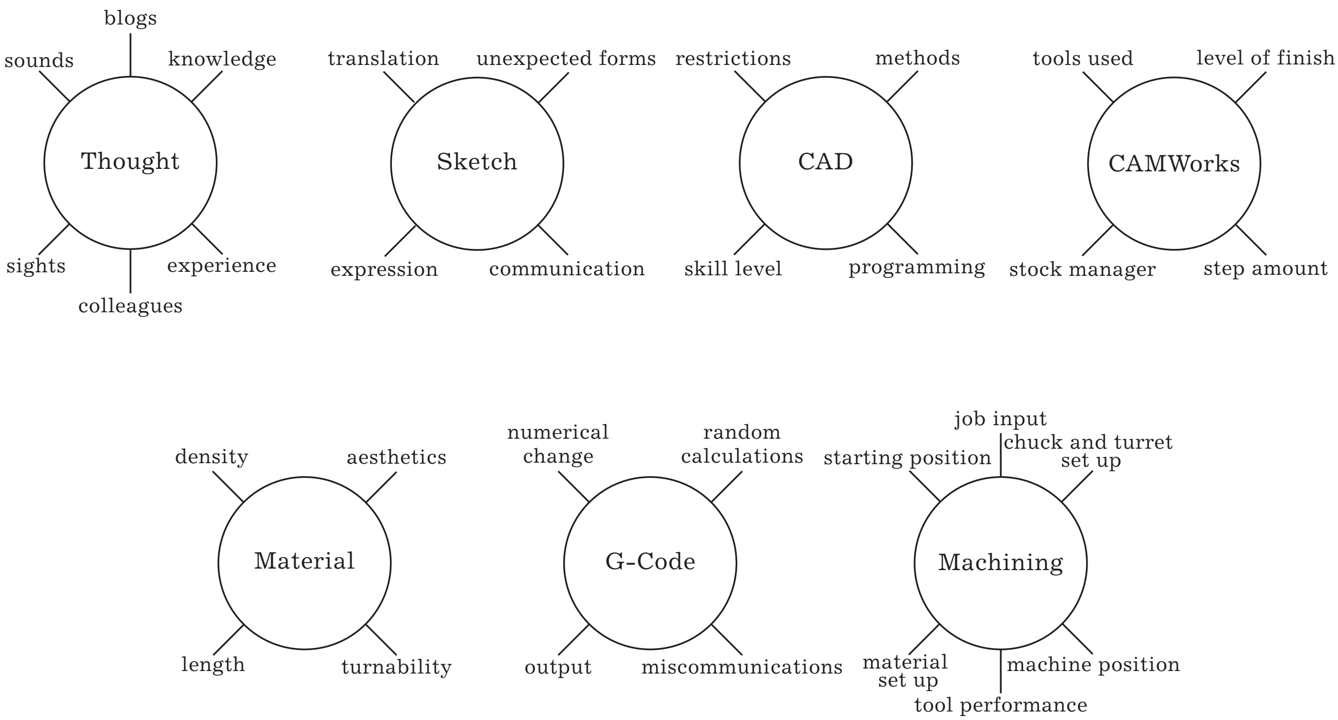

fig3. Design strategy for Serendipity

CAMWorks is a software package that is supported by SolidWorks for CNC processes. In this particular instance it is used to programme a CNC lathe roughing, finishing, grooving, threading, cutting, drilling, boring and tapping. The user defines a tool database according to the machine and then creates a CAD model to be generated, through a series of steps, into a text based code.

G-CODE

G-code is a text based language used in numerically controlled programming software. Used mainly in automation as part of computer aided manufacturing. It is the most widley used method of CNC programming sending instructions to a machine which tells cutting tools what tool is used, the cutting speed and path it needs to take.

```
%
O0001
( PART NAME=0.2 )
N1 G28 U0 W0
N2 (TOOL 1_DNMG-150608_Diamond 30deg back edge)
N3 G54 G40 T0101
N4 G50 S2000
N5 G99 G96 S200 M03
N6 G00 X200. Z3.04 M08
N7 X46.83
N8 G01 X41.75 Z.5 F.1
N9 X-2.792
N10 G00 Z3.936
N11 X200.
N12 Z100.
N13 G96 S150
N14 Z2.54
N15 X46.038
N16 G01 X40.958 Z0 F.05
N17 X-.792
N18 G00 Z2.54
N19 Z100.
N20 X200.
N21 G28 U0 W0
N22 M01
N23 (22MM JOBBER DRILL)
N24 G54 G40 T1515
N25 G50 S2000
N26 G99 G96 S150 M03
N27 G00 X0 Z100. M08
N28 Z1.
N29 G01 Z-15. F.05
N30 G00 Z1.
N31 Z-14.
N32 G01 Z-25.
N33 G00 Z1.
N34 Z-24.
N35 G01 Z-31.609
N36 G00 Z1.
N37 Z100.
N38 X200.
N39 G28 U0 W0
N40 M01
N41 (TOOL_7_Boring over 22 diameter A16QSCLCR09 check)
N42 G54 G40 T0707
N43 G50 S2000
N44 G99 G96 S150 M03
N45 G00 X23. Z100. M08
N46 Z1.5
N47 G01 Z-25.8 F.1
N48 G00 Z1.
N49 X23.918
N50 G01 Z-25.8
N51 G00 Z1.
N52 X24.835
N53 G01 Z-25.8
N54 G00 Z1.
N55 X25.753
N56 G01 Z-25.8
N57 G00 Z1.
N58 X26.671
N59 G01 Z-25.8
N60 G00 Z1.
N61 X27.589
N62 G01 Z-25.8
N63 G00 Z1.
N64 X28.507
N65 G01 Z-25.8
N66 G00 Z1.
N67 X29.424
N68 G01 Z-25.8
N69 G00 Z1.
N70 X31.35
N71 G01 Z-25.8
N72 G00 X27.234
N73 Z1.
N74 X30.842
N75 G01 Z-25.8
N76 G00 X27.722
N77 Z100.
N78 X200.
N79 G28 U0 W0
N80 M01
N81 (TOOL_10_Cut Off Tool 150.10-3N-14)
N82 G54 G40 T1010
N83 G50 S2000
N84 G99 G96 S150 M03
N85 G00 X200. Z-25.46 M08
N86 X57.23
N87 G01 Z-28. F.05
N88 X28.95
N89 G00 X71.75
N90 X200.
N91 Z100.
N92 G28 U0 W0
N93 M05
N94 M09
N95 M30
%
( PART NAME=0.2 )
( PROGRAM NUMBER=0001 )
( MACHINE=HAAS SL20 )
( CONTROLLER=HAAS )
( MATERIAL= )
( ESTIMATED MACHINE TIME=0 HRS. 8 MIN. 31 SEC. )
( STATION TOOL TYPE DIAMETER CORNER RADIUS DESCRIPTION )
( ------- --------- -------- -------------------------------- )
( 001 DIAMOND 055 000.40 TOOL 1_DNMG-150608_Diamond 30deg back edge)
( 015 DRILL 022.00 22MM JOBBER DRILL)
( 007 DIAMOND 080 000.80 TOOL_7_Boring over 22 diameter A16QSCLCR09 check)
( 010 GROOVE 003.00 000.20 TOOL_10_Cut Off Tool 150.10-3N-14)
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fig4. Example of g-code operations

C R A F T

Craft is the skill of doing or making something, craftsmanship relates to someone who practices a craft to a high level and develops skills in workmanship. David Pye interprets “craftsmanship as a workman using any kind of technique and apparatus, in which the quality is not predetermined, but depends on the judgement, dexterity and care which the maker exercises as he works.” (Pye, 1968). The particular concept of the idea is that there is risk during the process leading to what Pye labels as ‘workmanship of risk’.

fig5. David Pye in his workshop

D I G I T A L   C R A F T

The notion of digital craft refers to apply craft qualities and make innovative uses of digital technology, working on an object by experimenting on different ways of making and looking for unexpected moments to imbue an object with unforeseen qualities. The digital comes from the CAD software which is the tool to model with in the virtual realm, designers verifying models with physical CNC machined models and designing in the search of form. A change in the CAD software and a number of options when placing material into the machine as well as tool selection alters the result. The object produced by this method has an imprint left on it, unique to its mode of making, which creates an emotional response and increases the value it holds. Richard Sennett in The Craftsman describes “the people most skilled in using it (Linux open source software) are usually the ones thinking about the program’s ideal and endless possibilities” (Sennett, 2008) this application of skill comes from an understanding of the digital tool and using the machines vast array of possibilities.

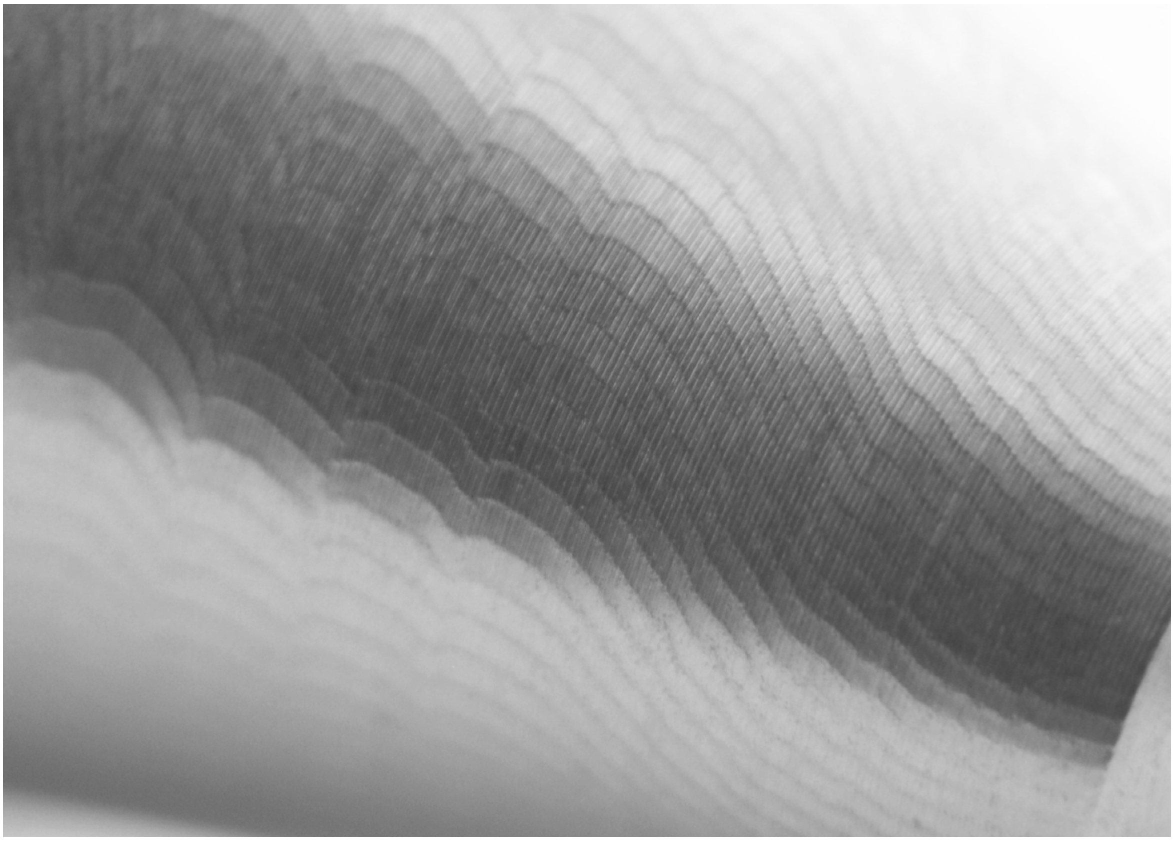


fig6. Digital Imprint

‘Modern design has taken over from craft, the making of functional objects of daily use by employing machines to do work once done by hand. Understanding the aesthetic and social implications of this transformation forces us to see craft as well as design in a new perspective” - Risatti, 2007

fig7. Machining in progress

3

history of the lathe

—3—

HISTORY OF THE LATHE

This section looks at the origins of the lathe to present day technology, looking at some of the manufacturing techniques and processes that were used throughout history. The basic principle of a lathe relies on a revolving work piece. Man has been using this motion for tens of thousands of years in the form of a drop spindle for weaving wool and a potter's wheel.

The first forms of the lathe appear to have been in use from the 3rd century BC. Created by the Egyptians with knowledge about the technology being limited but many objects revealing evidence of turning. A wooden bowl was discovered with tool markings creating the round form and a plugged hole in the center suggesting it had been placed between centres in a lathe.

The evidence is limited for this early object but progressing down the timeline there are signs of turned pieces throughout history only significantly advancing in the 14th century with more complex machines. The pole lathe, originating 14th century, was used to turn chair legs primarily and other parts. The pole lathe was often cited in the woods from where the raw material to be turned was abundant and accessible. The work was mounted between the centres and driven by a cord wound around; it didn't revolve continuously but oscillated backwards and forwards. Forwards when the tool was pressed down on the treadle lever and backwards when it is released, this motion was for each stroke.

This drew many frustrations and lead inventors to create the wheel lathe. The wheel lathe needed two men to operate it, one to provide the motive power and the other to do the turning operations. Another evolution provided the lathe with one live mandrel carrying the drive pulley; this allowed work that was hollow to be machined between the centres.

The lathe was generally made out of wood but by the end of the 18th century iron and other metals began to be used in their manufacturing. The use of heavier and more durable materials meant that the capacity to hold objects increased but it required the strength of two men to turn the driving wheel. Clockmakers developed lathes with great precision in the 18th century building machines that could produce intricate parts and at the same time became multi-purpose, capable of turning and gear cutting.

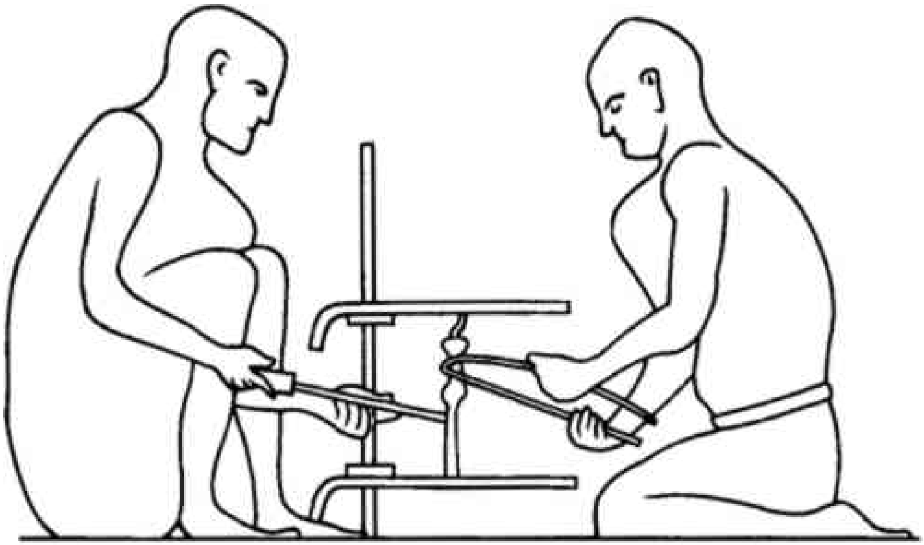


fig8. Egyptian Lathe

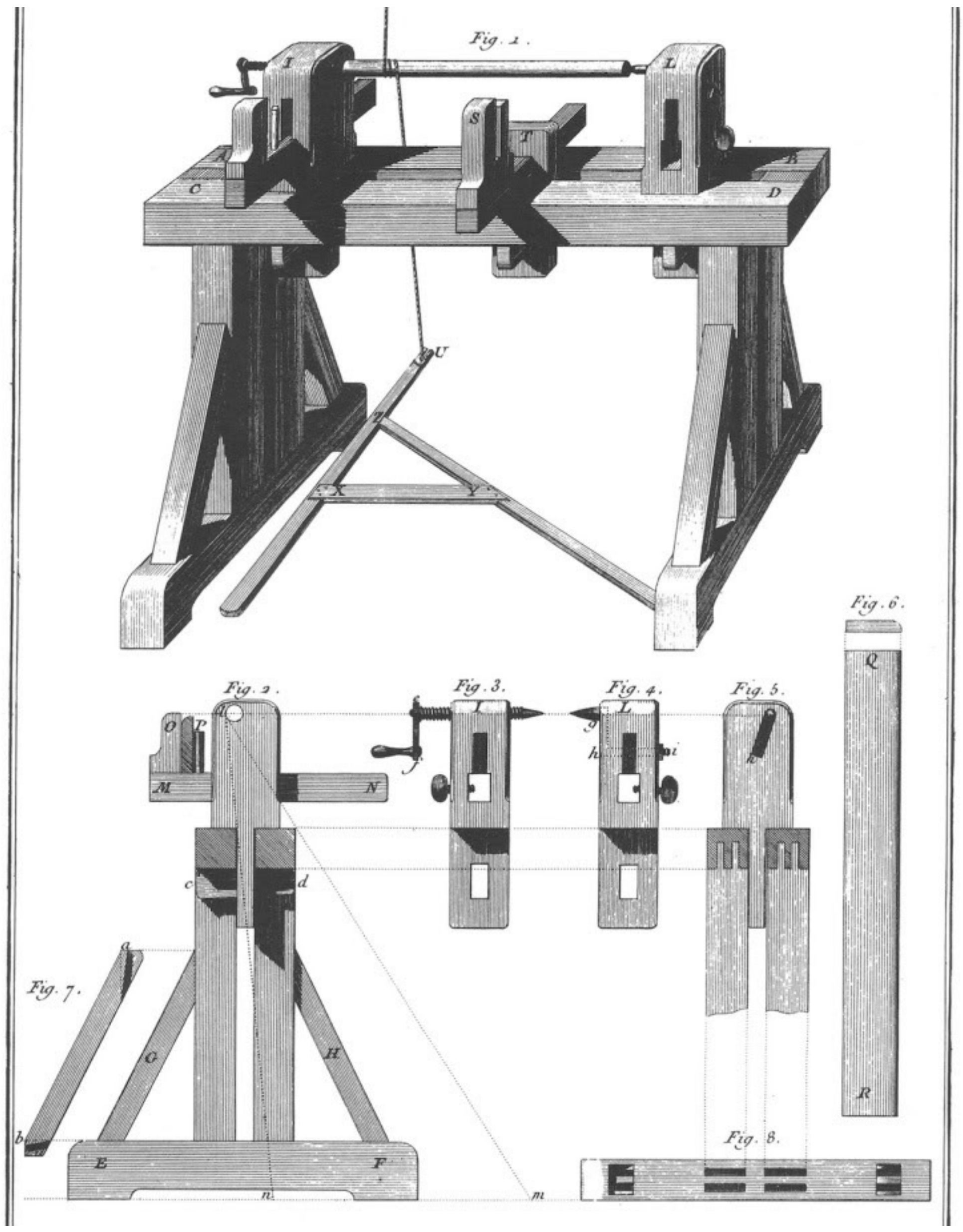


fig9. Pole Lathe

In some European countries in the last 200 years, water was used to drive lathes so that they could turn metal. By 1854 the waterwheel at Stott park bobbin mill had been replaced with water turbines. Turbines are much more efficient for milling with a large shaft mounted propeller submerged in a duct where the water flowed through, a series of gears drove the machine. In 1860 the internal combustion engine was created and years later it was small and reliable enough to use in lathes, this was popular with a lot of single and hobby 'turners' that had small workshops.

The treadle lathe was introduced with a new assembly connected through a pitman, with a crankshaft supported usually on centres fitted to the stand carrying the lathe bed itself. The driving pulley was made up from a heavy iron flywheel provided with grooves to accommodate a round leather belt, which transferred power to the mandrel. Leonardo Da Vinci was said to have produced drawings for a treadle lathe but, as with his many suggestions, there is no evidence it was constructed at the time.

At the end of the First World War in 1918 the Vershoyle mandrel was available, this machine was small and was similar to the wheel lathe, and it had the same drawbacks as the wheel lathe. It was not a huge success and was quickly taken off the market.

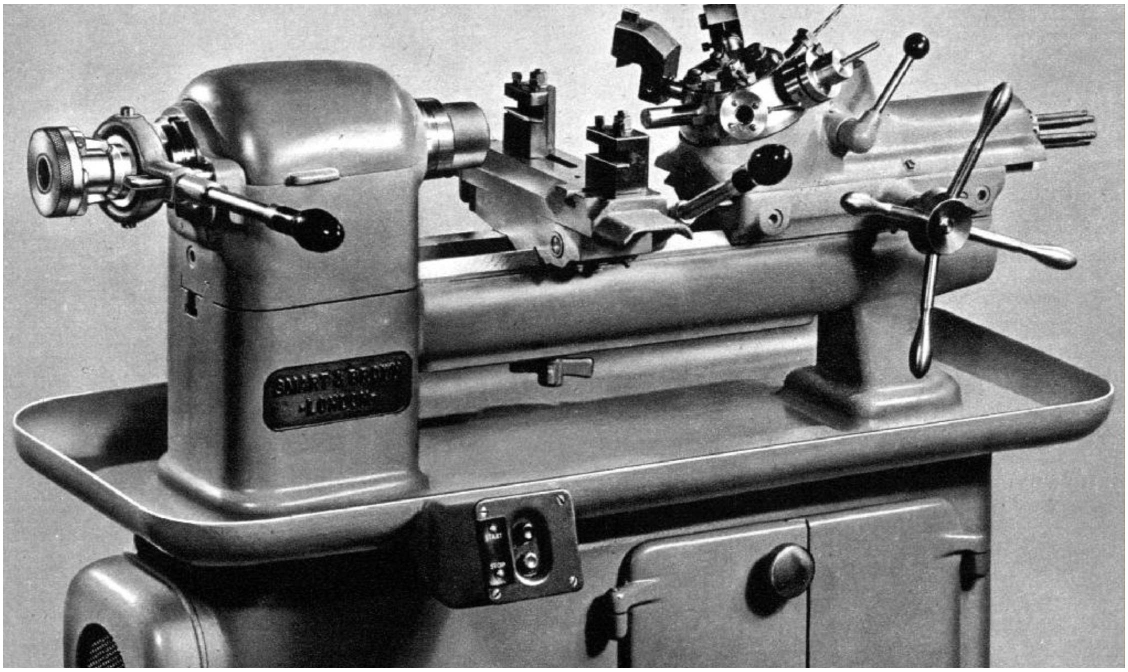


fig10. Clockmakers Lathe

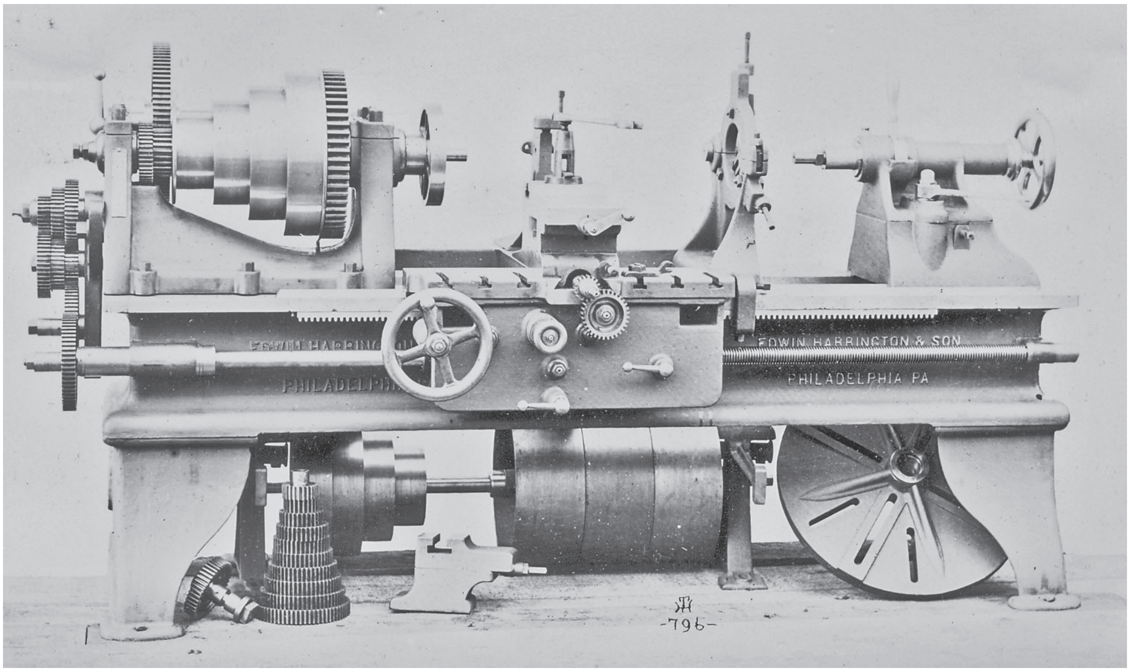


fig11. Twenty-five inch lathe

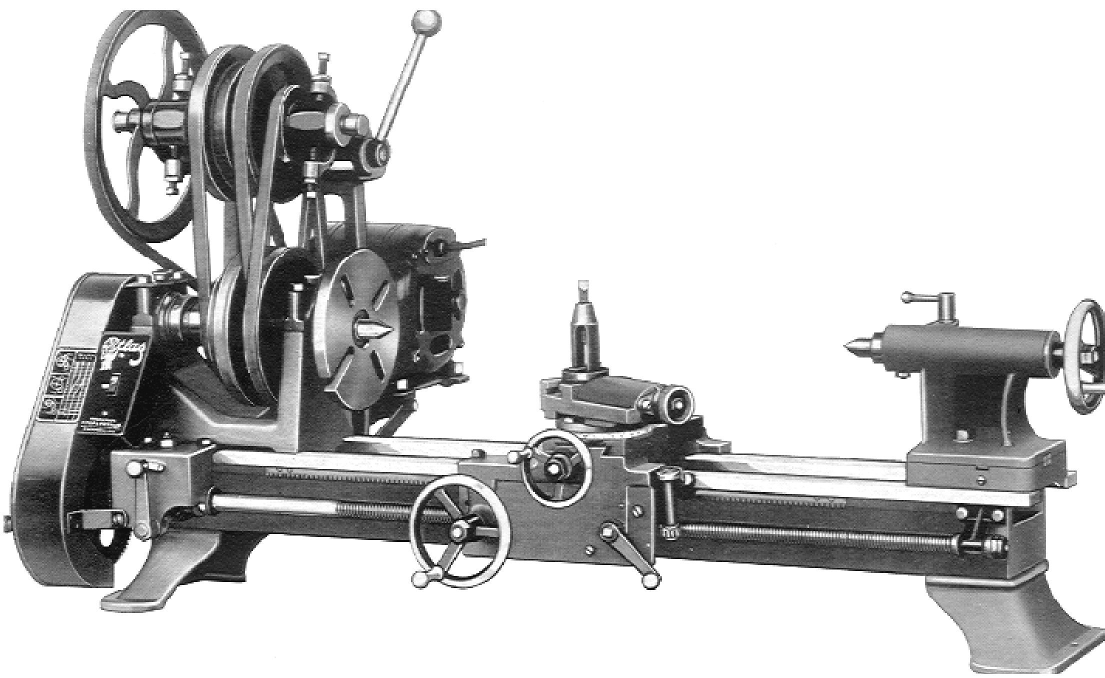


fig12. Atlas 9-inch lathe

The technological revolution brought in new materials and more importantly electricity. A process of electricifcation took place changing power sources over in factories for a more efficient system. This allowed for an electric motor to be placed on a lathe for powerful metalworking.

By the middle of the 20th century self-contained lathes with integral electric motors having stepped pulleys were developed and manufactured. It was something that caused John Parsons to attach a servomotor to the x and y axis controlling them with a computer that read punch cards to give in positioning instructions in 1952.

Todays machines have a microprocessor in each machine that reads a CNC controlled text based code the user creates and performs the operations. The tool turret moves in two axes, X and Z, X is front to back and Z is left to right movement. CNC lathes can perform many different types of operations and can go up to 50,000 revolutions per minute. There are some lathes that offer live tooling, which is a process in which a lathe can perform milling operations while the spindle has stopped. In addition most CNC lathes offer placement for a number of tools in a turret for different types of turning operations that can be calibrated quickly.

fig13. Servomotor

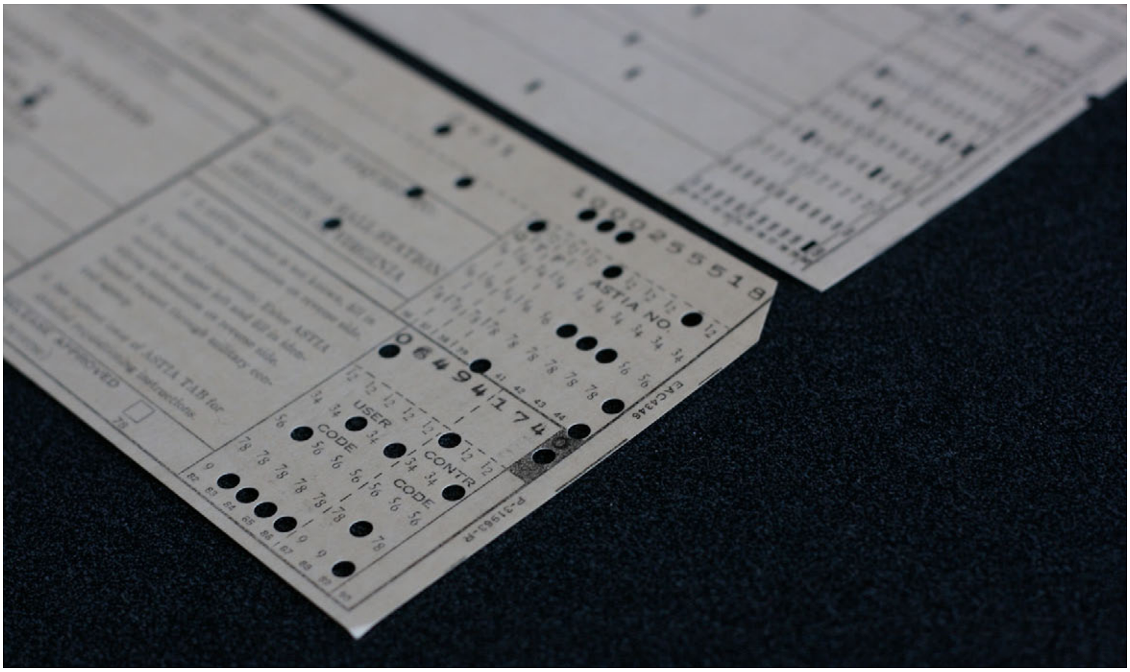


fig14. IBM Punch Cards

fig15.VUW's Haas CNC Lathe

4

aims & benefits

4

AIMS & BENEFITS

The aim of this research is to gain a clear and concise understanding of the CNC lathe at Victoria University's School of Design. Using the machine in this surrounding allows me to have access to it for the duration of the thesis giving me sufficient time to explore new methods within the software and create objects that will exercise various capabilities of the lathe. One example could be the material you choose and its properties, whether it is easy to turn could alter the output by making the machine work harder and vibrate. This would add the intrinsic value of craft that Glenn Adamson talks about "craft might be more usefully conceived as a process" (Adamson, 2007). Another example is making changes in the G-code, this alteration could change the patterns of the turning process and give a truly 'serendipitous' moment when the machine finishes and you can open the sliding protection door to reveal the object and see unexpected results. Each object will be analysed and catalogued for the unique quality it has with both successes and failures inscribed into them.

The knowledge gained will benefit a range of people from emerging designer to current designers looking at new techniques using digital mass manufacturing technologies. It includes anyone from; industrial designers, engineers, computer and workshop technicians, students, architects and artists. The research will assert that a designer's creativity plays a vital role in the heart of the manufacturing process. The study looks to create the circumstance in which a connection between design and machine can be described as 'digital craft'. The background to my study stems from Tim Millers' research that tested numerical changes within g-code that resulted in beautiful spiralling qualities and also his Victoria University INDN 211 paper in which the students had to include a CNC turned component. This experimentation brought about the idea of how professionals could view this work as a window of opportunity to exercise creativity through digital manufacturing and at any scale of making. I would take the valuable knowledge gained from this process and apply it to any other form of digital technology.

5

design research

5

DESIGN RESEARCH

David Pye (Pye, 1968) argues that mass production has introduced uniform and mundane products that lack the individuality of workmanship and craft. At the School of Design we have been taught to use mass production tools to create individual pieces, as traditionally uniformity was the goal. Pye uses the word craftmanship and explains it as meaning workmanship using any kind of technique or apparatus, in which the quality of the result is not predetermined, but depends on the judgement. 'The workmanship or risk' is the result of every operation during production being determined by the workman as he works and its outcome depends wholly or largely on his care, judgement and dexterity. There has been no correspondence with interest in workmanship as modern invention has seen a decrease in craft; Pye states "an operative, applying the workmanship of certainty, cannot spoil the job. A workman using the workmanship of risk assisted by no matter what machine-tools and jigs, can do so at almost any minute"(Pye, 1968). He expresses the merits of risk "there is something about the workmanship of risk, or its results; or something associated with it; which has been long and widely valued". Stating that each object has become so uniform and nearly all lack tactile and aesthetic diversity. Workmanship of risk needs to be understood and appreciated for the art it is. 'The love of imperfection as a measure of perfection' (Pye,1968).

"The love of imperfection as a measure of perfection" - Pye, 1968

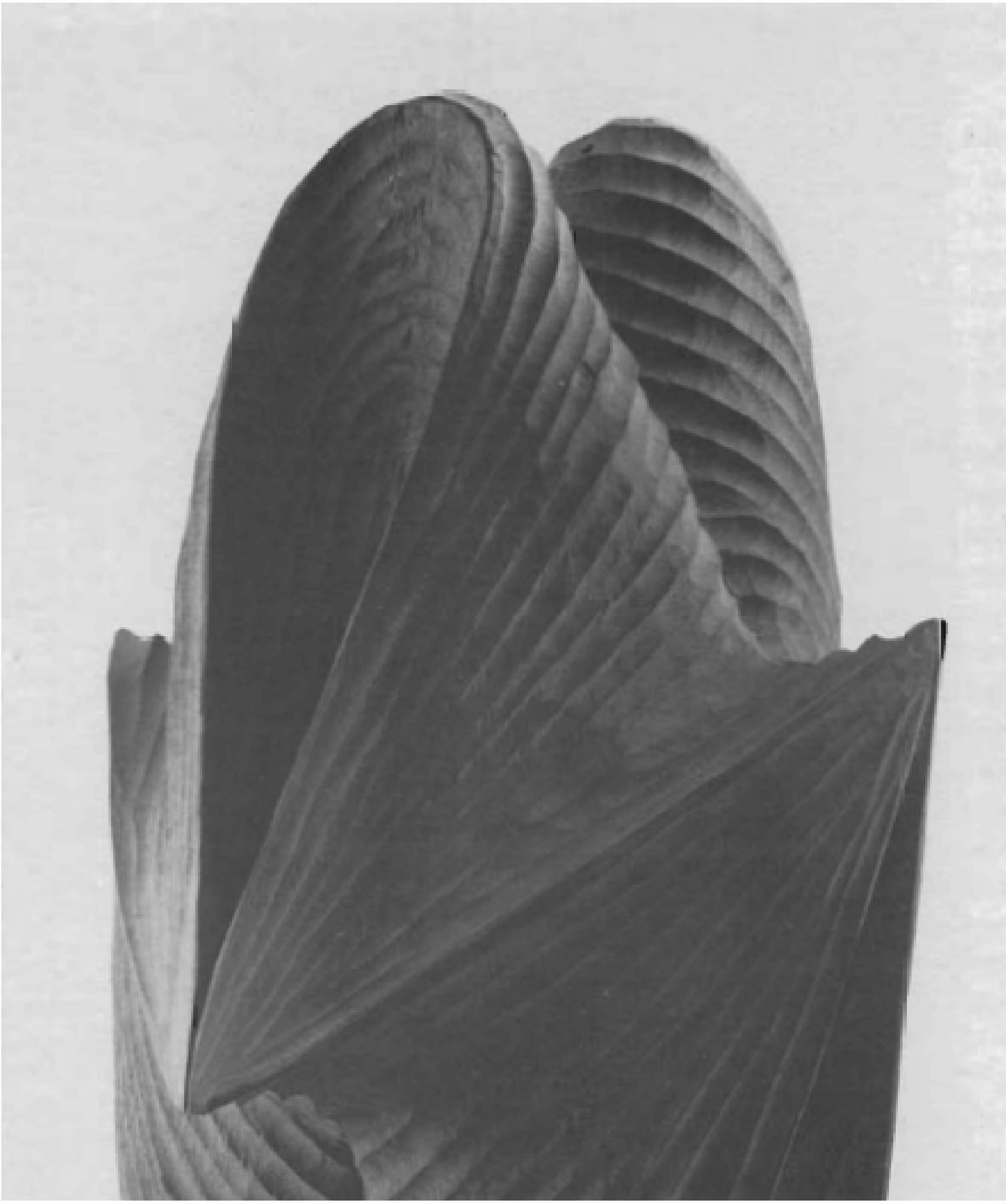


fig16. David Pye's Owl in English Walnut

Inspiration for the research topic came from my undergraduate study in the interest of manufacturing processes from Victoria University courses INDN211, INDN212 and INDN311 coordinated by Tim Miller, Edgar Rodriguez and Ross Stevens respectively. Each one of these courses encouraged students to work with different manufacturing processes so that we could all gain a wider knowledge of skills; this overview of past courses was the catalyst in deciding this research topic. At 2012's DeSForM conference there were a lot of interesting papers presented from designers and academics around the world, in particular the paper 'Digital Craft in Digital Space: A Paradigm Shift in the Making' presented by staff members at Victoria university had many parallels to this research and related to digital craft. The paper looked at technological innovation and digital craft within industrial design at VUW, speaking about how the design process and our roles as designers have evolved significantly. An article in the economist states that we are now entering the third industrial revolution where manufacturing is going digital and boundaries are being stripped away. Howard Risatti states "modern design has taken over from craft, the making of functional objects of daily use by employing machines to do work once done by hand", he further says "understanding the aesthetic and social implications of his transformation forces us to see craft as well as design in a new perspective" (Risatti, 2007).

Through further research I found two additional papers 'Beyond the Smooth: CNC Machining with Meaning' (Miller, 2007) and 'Tectonics to Tectonics: An Interdisciplinary Exchange of the Concept' (Petrovic, Fraser, Miller, Perkins, & Stevens, 2007). These introduce the term 'digital tectonics' within the realm of industrial design. Both papers present how understanding materials and manufacturing processes can present new tectonic possibilities. Tectonics is often seen in architecture at a large scale and the idea of using an industrial design scale to focus on the smaller details, architecture learning from industrial design and vice versa. The idea is that the emphasis shown to material quality and processes to initiate an emotional attachment to an object to increase the 'longevity by design'. The conclusions engages the relevance of tectonics to the heavily criticised anonymity of mass production, encouraging a trend of using digital technology to enrich design through conceptual and practical approaches.

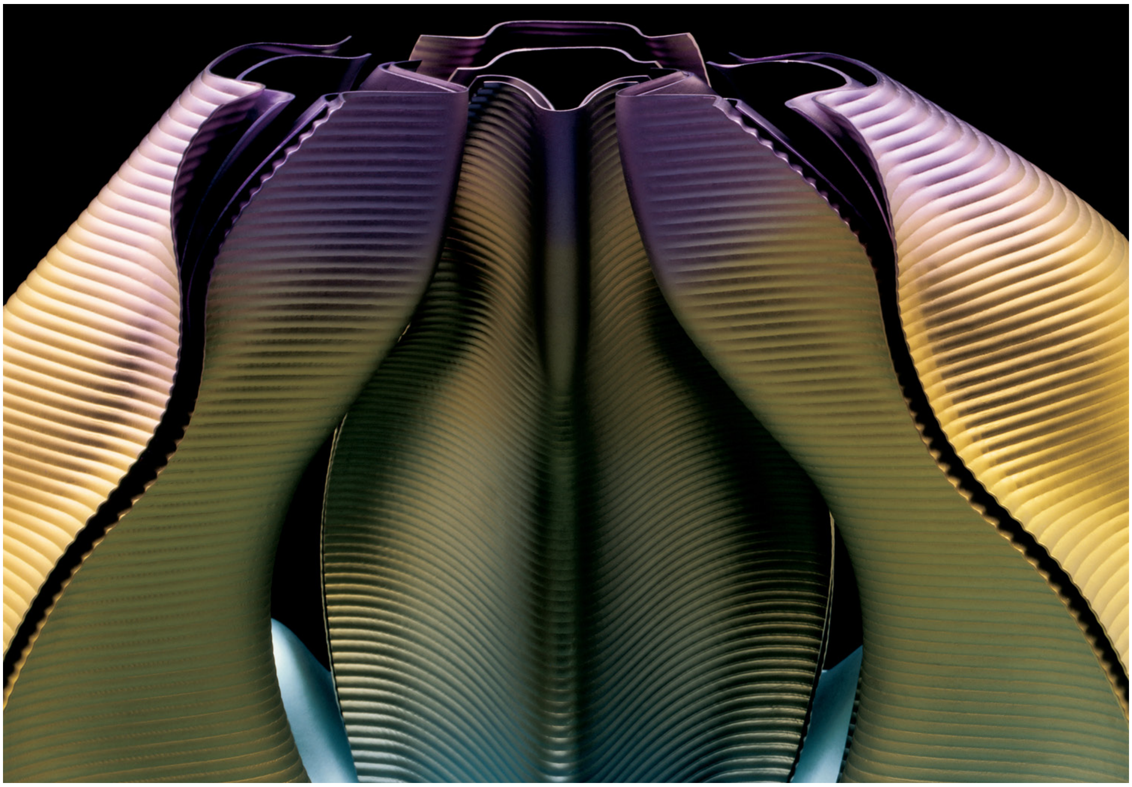


fig17. Greg Lynn's Tea and Coffee Towers

fig18. 3D printed tectonics and electroplating in copper

'Making the future" in the economist (the Economist, 21.4.2012) raises issues surrounding the shift of the car making industry to Japan in the 1980's with America striving to catch up to the Asian market. America, specifically Detroit, proposed 'lights-out' manufacturing where the factories would be completely automated so that the lights could be turned off and the robots left to continue working. This was all but a dream and Japan's success was not in the efficiency of their machines but in the integration of the individual with the machine, as they kept the robots supervised at certain period of time. "All these automated machines require someone to service them and tell them what to do. Some machine operators will become machine minders, which often calls for a broader range of skills" illustrating that some industries will still try to replace people but there are corporations that will look to make the machine and people 'colleagues'.

fig19. Mass Manufacturing with human interaction

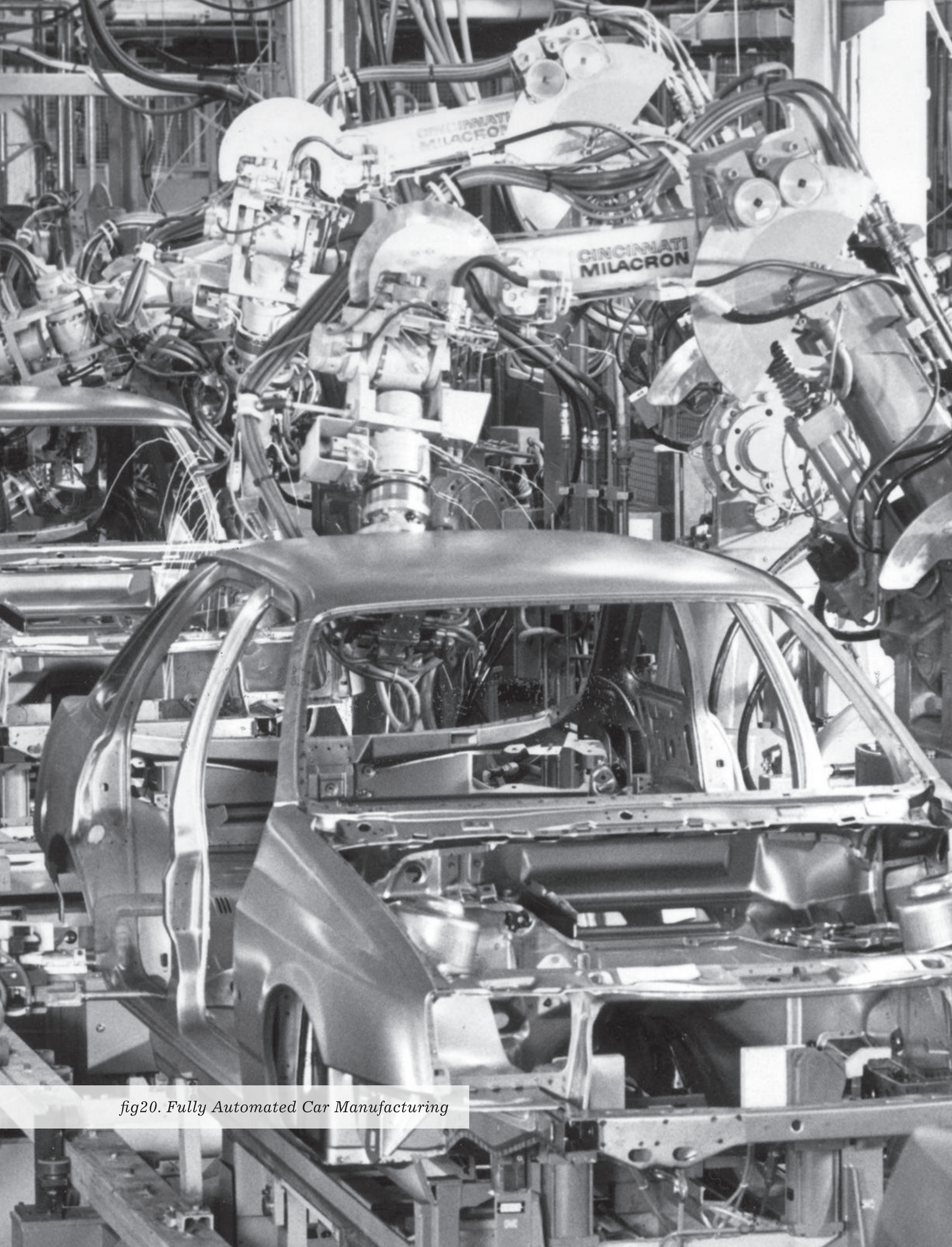


fig20. Fully Automated Car Manufacturing

“The rise of conceptual design and a resurgence of craft, either in opposition to or conjunction with mass-production, means that design can be judged on pure creative merit. just like works of art” - Houseley, 2009

‘Digital craft in digital space’ sites the work of Dan Emery’s that explored the potential of the laser cutter. His thesis was titled ‘Craft without Hands’ and this carried the same idea that David Pye talked about in monotony in mass production. He shows a great example of honing in skills and show mastery in a subject where he limited himself to materials like MDF and extruded plastic sheets. The paper describes Dan Emery as “reminiscent of the apprentice gaining an intimate understanding of his tools”. This, now all but lost, tradition enables a student of the profession to master his skill through practice. He looks at how computers and digital technology has impacted the relationship between man and the medium, being the product. “Elements such as tactile qualities; temperature and smell, and three dimensional qualities; including sense of space and the relationship to form to the body are aspects that can only be assessed through physical experience” (Emery, 2005). Digital technology is evolving at an increasing rate but each improvement a new skill can be learnt, the economist predicting “the days when projects ground to a halt for want of a piece of kit, or when customers complained that they could no longer find spare parts for things they had bought, will one day seem quaint” (the economist, 21.4.2012). His research showed the values of craft within present society and the current shift of people wanting to reconnect with the values apparent in craft based methodology in context with current and future production methods “The rise of conceptual design and a resurgence of craft, either in opposition to or in conjunction with mass-production, means that design can be judged on pure creative merit, just like works of art” (Houseley, 2009). The aspects of craft that are of high value to people are the way it preserves the fingerprints of the creator, physically or metaphorically. This starts to look at re-establishing the connection between the object and the user with a ‘one off’ piece. He labeled classes of craftsman from the amateur to the master professional which was associated with ‘creative craft’ defined as being someone who will continually work on a product until they have reach a level of satisfaction they deem ‘complete’. The process of this work finds new and unexpected incidents of form creating a wide variation of objects. The first part of Emery’s process looks at tacit knowledge by learning the software and hardware for himself and conducting abstract experimentation before achieving a developed level of understanding for the technology. In his conclusion he says “The objects are to express knowledge of the technique and the qualities specific to this technique that will provide maximum richness and value”.

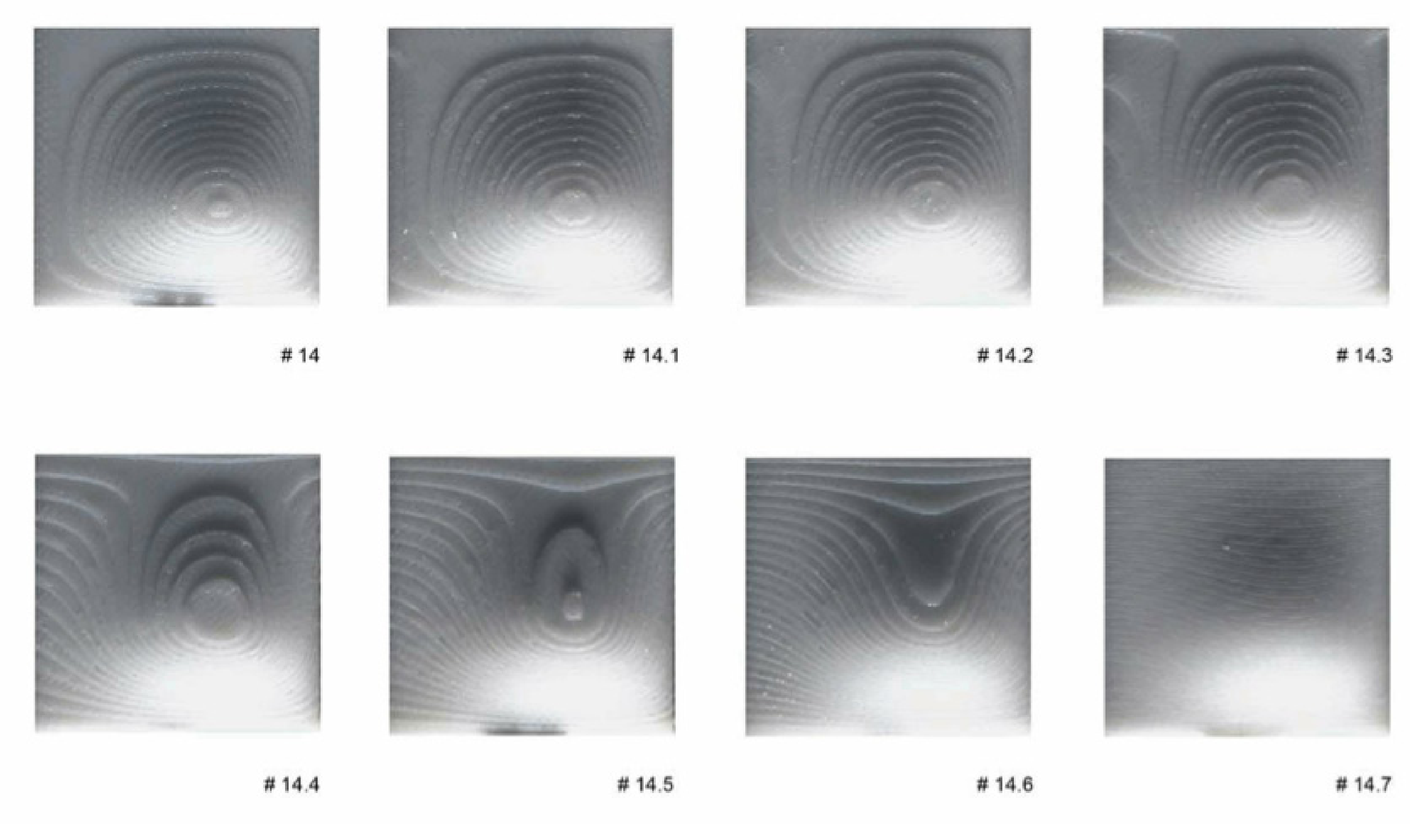


fig21. FDM Models showing tectonic patterns from Ross Steven's 'Worn Out or Worn In?'

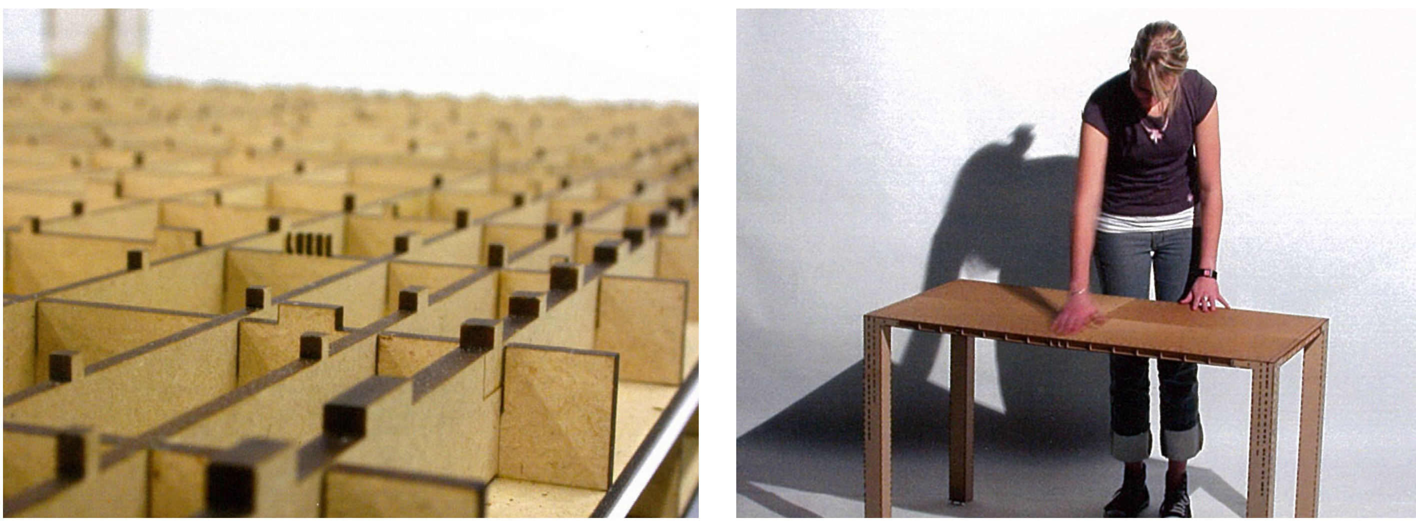


fig22. Dan Emery's Final Model from 'Craft Without Hands'

Wabi-sabi is a Japanese philosophy best described In a Zen tale of a man walking and coming across a hungry tiger, which chased and cornered him at the edge of a precipice. The man jumped to avoid the impending danger and in doing so managed to catch the branch of a tree. While he hung there wondering what to do, he noticed a second tiger at the base of the tree, waiting for him to fall. As his strength began to flee the man saw a wild strawberry growing within his reach, he gently brought it up to his lips and acknowledging that it would be the last thing her ever ate, he noticed how sweet it was (Juniper, 1967). This original philosophy talked about the true essence of beauty that lies in the brief period of time between the coming and going of life, the ups and down as part of human nature. Ever since the thirteenth century Monks brought together the disciplines of art and philosophy, which have become inseparable merging into a way of life for many of the Japanese people. The word has many principles, such as impermanence, humility, asymmetry, and imperfection seeking beauty in the natural order of things. This method pays attention to a material culture showing physical evidence of a relationship between people and their possessions.

fig23. Wabi Sabi for Artists by Leonard Koren

"Wabi-sabi is a beauty of things imperfect, impermanent, and incomplete. It is a beauty of things modest and humble. It is a beauty of things unconventional." - Koren, 1994

fig24. Wabi Sabi Pottery

fig25. Tom Dixon's Eclectic Range shaped by hand expressing the tool marks and exploring with materiality

The readings by Ken Friedman and Pieter Jan Stappers used keywords such as 'research into, by and for design' and 'doing design as a part of research' (Friedman, 2008) (Stappers, 2007). 'Doing design as research' refers to the process of creation and how it can offer you insights into areas that you only theoretically planned for, it raises problems to solve and sometimes-successful strategies. This is known as tacit knowledge, which is knowledge you gain from the process of designing.

fig26. Dunne and Raby Technological Dream Series providing playful objects to interact with

In the documentary 'Objectified' (Hustwit, 2009) there are many of the world's top designers talking about industrial design with regards to mass production and its impact. It starts off with Jonathon Ive saying "when you see and object, you immediately make so many assumptions about that object" a true statement as so much of product design's success if about the immediate impression it makes on a consumer. This is where the designer thrives knowing what the consumer wants even before they know themselves. Mass production has been about for centuries in various forms with the earliest recorded being the first Chinese Emperor who noted that his archers made their own arrows customised to their bow. When they died the remaining arrows were useless to every other archer as it wouldn't fit to their particular bow, so the Emperor standardised bow and arrows so that all archers could use them. The ultimate goal of industrial design has always been mass production, but with mass production the designs have moved from tangible to intangible but within the current climate the shift towards tangible design is returning. New breeds of designers are using machines to craft, much like the old craftsmen but with different tools. The notion of craft to an object adds value and value comes from an individual element in the design. Dunne and Raby mention that "people want more interesting things" things that give you a clear sense of the people who made it and why, Henry Ford is noted saying that "every object tells a story" and that is what really gets people involved.

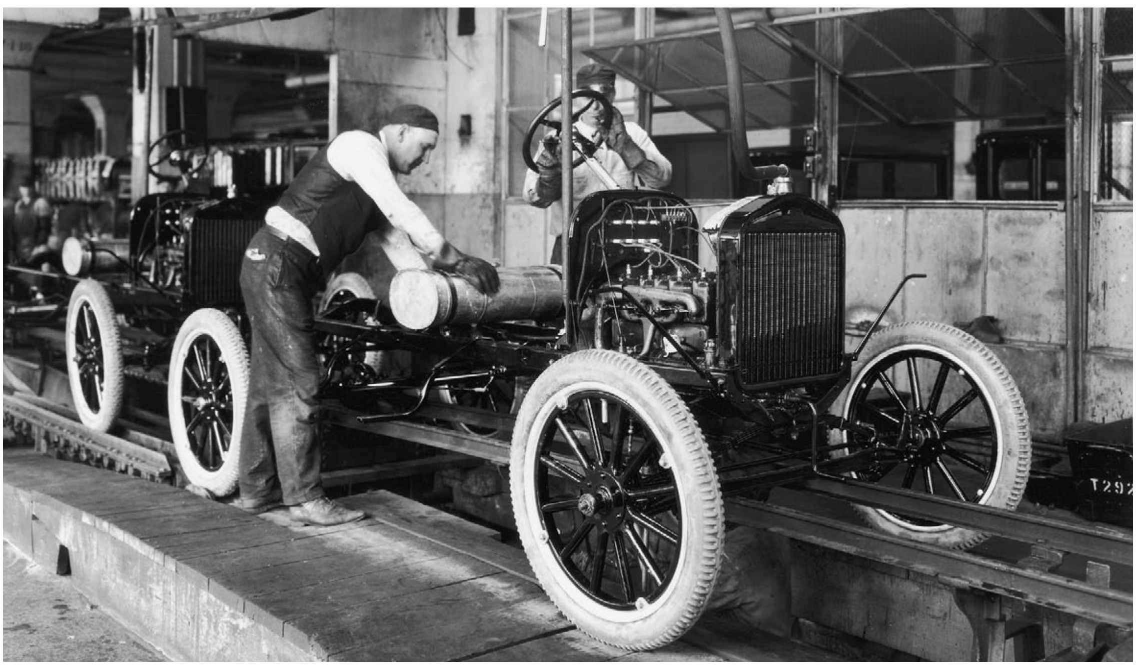


fig27. Henry Ford's assebmly line of the Ford Model T

There are similar designer processes and disciplines that look at and recognise serendipitous moments. For example Santiago Calatrava who conducted rigorous experimentations testing his design configurations to breaking point and evaluating his failures as methods to improve his designs. “By creating these real and apparent conditions, Calatrava seems to enjoy, like an acrobat or a shrewd dancer, a delight that offers cognitive pleasure” (Tzonis, 1999) this explanation is a great way to describe how Calatrava is always open to experimentation in his discipline of Architecture and Design. In ‘Elements of Design’ Gail Greet Hannah relates design to Hip Hop music “Hip Hop music, is based as it is on sampling and composing new and pre-existing tracks and giving them a finishing varnish or surprising novelty” (Hannah, 2002). This particular choice of comparison mimics how most designers create, sampling other designs as inspiration and composing new designs with pre-existing elements.

‘The Design of Design’ (Glegg, 1969) relates to the topic closely as it talks about a time where failures and success were even and permanent markings to be analysed and regenerated. He states, “a designer’s life is an unpredictable pattern of the challenging and the enthralling, of adventure and achievement; even learning how one need not be necessarily dull”. He also has a beautiful quote, which directly relates to how my experiments will be viewed “his successes and sometimes failures become incarnate in metal. They grow up and confront him, sometimes with surprising results”. Gordon Glegg also talks about serendipitous trains of thought which can happen in any environment and back in the 60’s he speaks about ideas coming to him while half asleep in bed, out walking or riding, Travelling, in Church, at a state dinner, sitting in front of a fire or listening to music. It is the state of relaxation where designers often come up with brilliant ideas, perhaps because in these contexts they put the problem in their subconscious, “the secret of inventiveness is to fill the mind and the imagination with the context of the problem and then relax and think of something else for a change”.

"His successes and sometimes failures become incarnate in metal. They grow up and confront him, sometimes with surprising results" - Glegg, 1969

This idea of using a method where the mind is allowed to wander and present solutions to oneself carries over in the remaining readings along with the idea of keeping a thorough process "doing design, through making prototypes, testing prototypes, visualising tools and systems" (Inns, 2010). Tom Inns lists a number of ways to describe the type of design this topic will embark on 'Auspicious (focuses on the affirmative, optimistic and serendipitous), Opportunity-making (uncovers unexpected potential for elsewhere), reflexively innovative (holistic innovation acknowledging interdependence) and self-steering (adapts by re-languaging its own working language). Relating this alongside Nigel Cross's model of the design process of exploration, generation, evaluation (back to generation for multiple experiments) and communication of the design once there is a finalised design or series of designs. My understanding of this lead me to create my own philosophy of creativity, discovery and innovation able to be recognised with help from the French chemist microbiologist commenting on his discipline "in the fields of observation, chance favours only the prepared mind" (Pasteur, 1856). This means one has to be alert for the randomness of chance and serendipitous moments, the richness of the tools being used and the design intention then ready to be prepared to use the 'aha' moment and make a discovery.

There are many design influences that have shaped my aesthetic values, philosophies and methods, which have also made their style of design into an art form. The three in particular are Dieter Rams and Ronan and Erwan Bouroullec who have made recent books about their philosophies, processes and passions. There are many things you can say about Dieter Rams' work, "The completeness of the relationship between shape and construction, material and process, defines his work and remains a conspicuously rare quality" and "Dieter Rams succeeded in making his philosophy tangible by giving form and, ultimately, the relevance of mass production to his ideas. He remains utterly alone in producing a body of work so consistently beautiful, so right and so accessible" (Lovell, 2011). His work really does speak for itself, it show pure consideration to the finer details and the little things that give a product so much character and longevity "my heart belongs to the details. I actually always found them to be more important than the big picture. Nothing works without details. They are everything, the baseline of quality". It is his attention to the minute details, surface qualities and colours that make him stand out. Lastly Lovell talks about Dieter's beautiful way of explaining how the relationship with the machine brings him closer to being an engineer "it is more about being a 'Gestalt-Ingenieur', an 'engineer of form' or 'technically orientated designer'".

Ronan and Erwan Bouroullec apply the process of thought and experimentation with designs flowing from research through to manufacture "for the Bouroullec Brothers, this intuitive process of 'cloud teasing' is paired with a natural impulse to question everything. Add to that their curiosity about new materials and industrial production processes, as well as their shared vision regarding plastic beauty, you have quite the combination" (Koivu, 2012). It could be argued that serendipity comes into their work when Koivu talks about "free experimentation with different techniques and technologies can result in discoveries that find their way - in simplified forms or a partial detail - into products adapted for large-scale production". Their work showcases the benefits of keeping the mind active, consciously, with the design process or subconsciously, outside of design.

“It is more about being a ‘Gestalt-Ingenieur’, and ‘engineer of form’ or ‘technically orientated designer” - Lovell, 2011

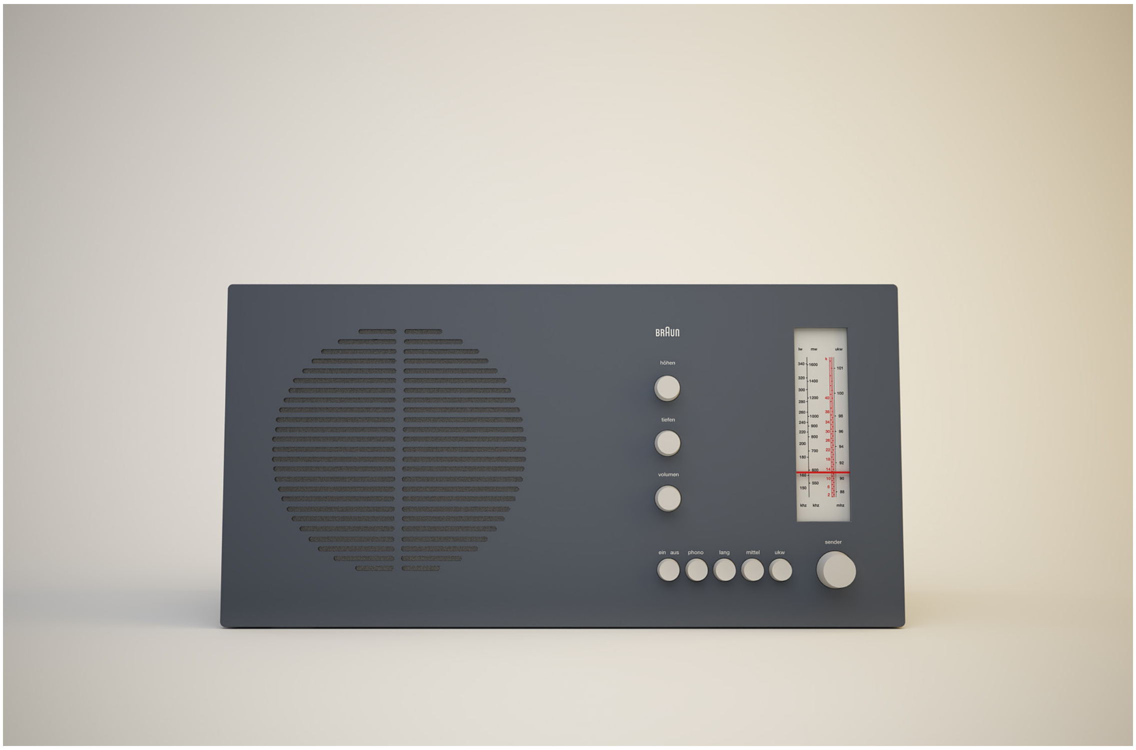


fig28. RT20 Tischsuper Radio

fig29. Dieter Rams’ Vitsoe Shelving System

fig30. Bouroullec Brothers experimenting with fabric and connections, pushing the boundaries

fig31. 'Bivouac' at the Centre Pompidou-Metz

6

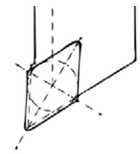
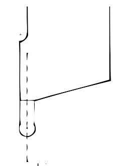
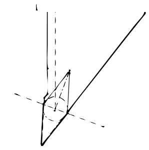
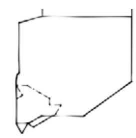
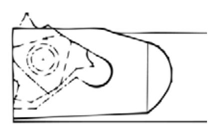
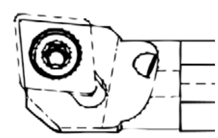
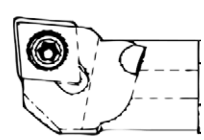
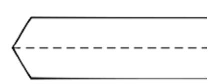
experiments

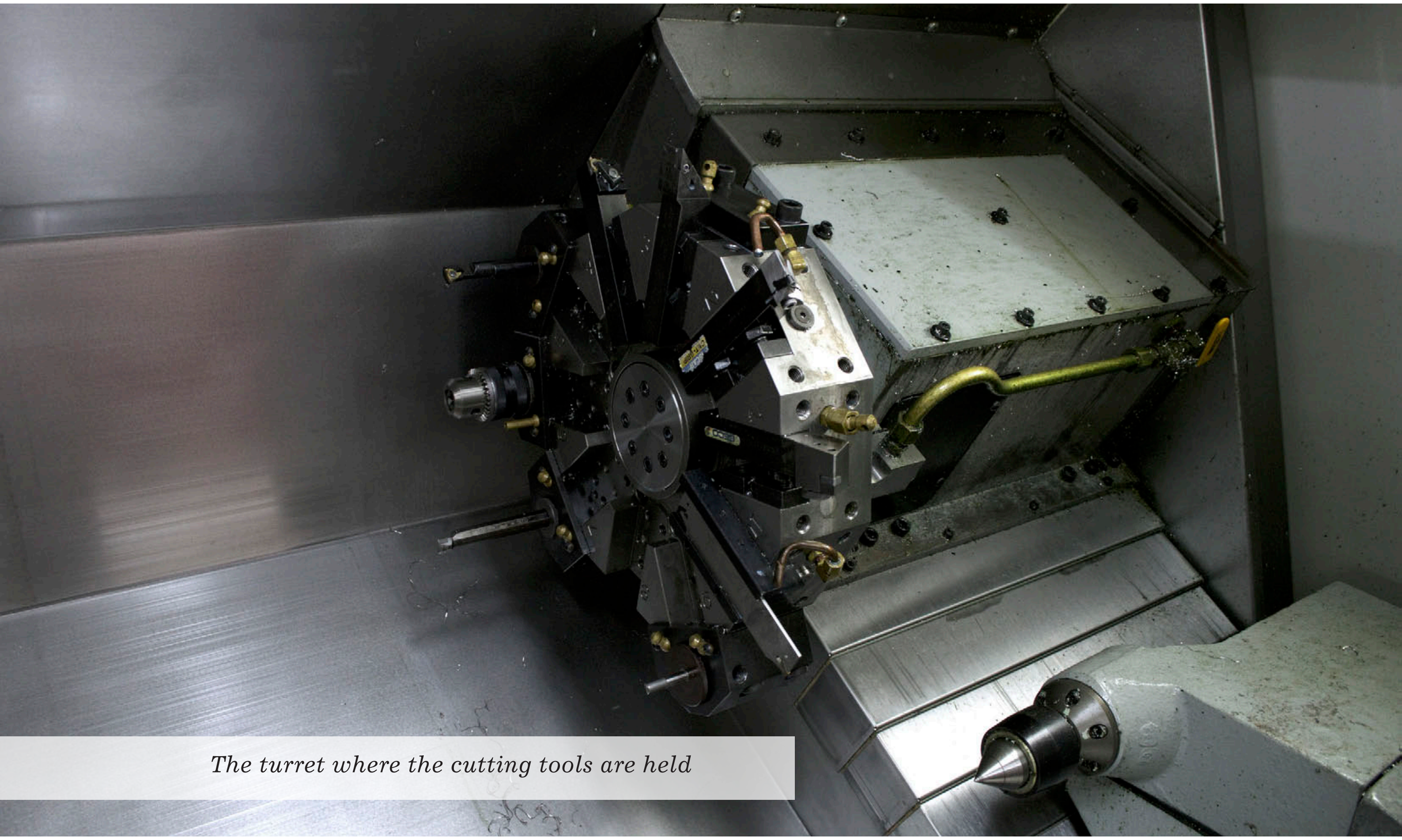
6

EXPERIMENTS

This chapter will outline the stages of my design process in chronological order, depicting what happened in each experiment and analysing the results. The design research started with learning CAMWorks within SolidWorks, understanding the procedure one goes through when making a model in the CAD software. Transferring to the CAM software to define the machining process, simulate these and generate G-code for the machine to read. Through the process of simulating the tool path I was able to see the surface qualities of the machined objects in a virtual environment. The first step was to create a series of ornamental abstract experiments to determine the nature of the CNC lathe and its limits and constraints. Victoria Universities' metal workshop technician, John Hawkins, took me through the process of CNC machining on the Haas lathe and showed me some techniques of tricking the machine within the text code, and physically, with the machine. He also taught me how to operate the machine from start-up, to calibration, machining and shutting down. I started with testing the spline deviation, vibration, material qualities, spiralling and just pure forms to see what my results would be. These experiments took place to explore machining qualities and gain a comfortable level of skill with the machine. The knowledge gained through this process informed me about particular qualities and how to control serendipity using examples from Stephen Makri on the unexpected, insightful and valuable moments to identify a feature, realise its potential, design using the method and manufacture accordingly. The range of materials used were different grades of aluminium, stainless steel, mild steel, brass, bronze, copper, acrylic, acetol, nylatron and ertalon, each one revealed a different expressive quality brought out by the lathe.

T O O L C R I B

tool 1	Sharp edge with a wide angle to help cut through tough materials.	
tool 2	Two Styles, one with a radius all around the tip and the other with a radius and two flat sides.	
tool 3	Sharp edge and acute cutting angle for detail finishing.	
tool 4	External thread cutting.	
tool 5	Internal thread cutting.	
tool 6	Jobber Drill 13mm diameter.	
tool 7	Boring over 22mm diameter.	
tool 9	Boring between 13-21.9mm diameter.	
tool 10	Cut off tool / Parting tool	
tool 15	Larger Drill pieces 22mm (tool 6 commonly used).	



The turret where the cutting tools are held

Control panel of the CNC lathe

FIRST SERIES

The first series of testing commenced the study by investigating a few forms that would give me a clear connection from computer generated models to physical objects. Using low cost materials, such as mild steel and aluminium allowed for quick experiments. The forms used are most likened to a tamper, linear, chess and dome profile, initially looking at vibrations, tool precision and spline deviations. These are some of the results:

+ The results in the series offered varied effects with each tool in the machines turret cutting differently when producing clean machining, tool 1 cutting roughly through the material and leaving a few blemishes, tool 2 and 3 cut with clean finishes but tool 2 had a bit of wear from previous jobs so there was evidence of the tool left behind.

+ Vibration was evident on a few pieces due to the material length protruding out of the chuck and the speed of revolution causing the stock to oscillate creating a visually striking Moire pattern and deeply engraving into the metal when protruding out in excess of 200mm.

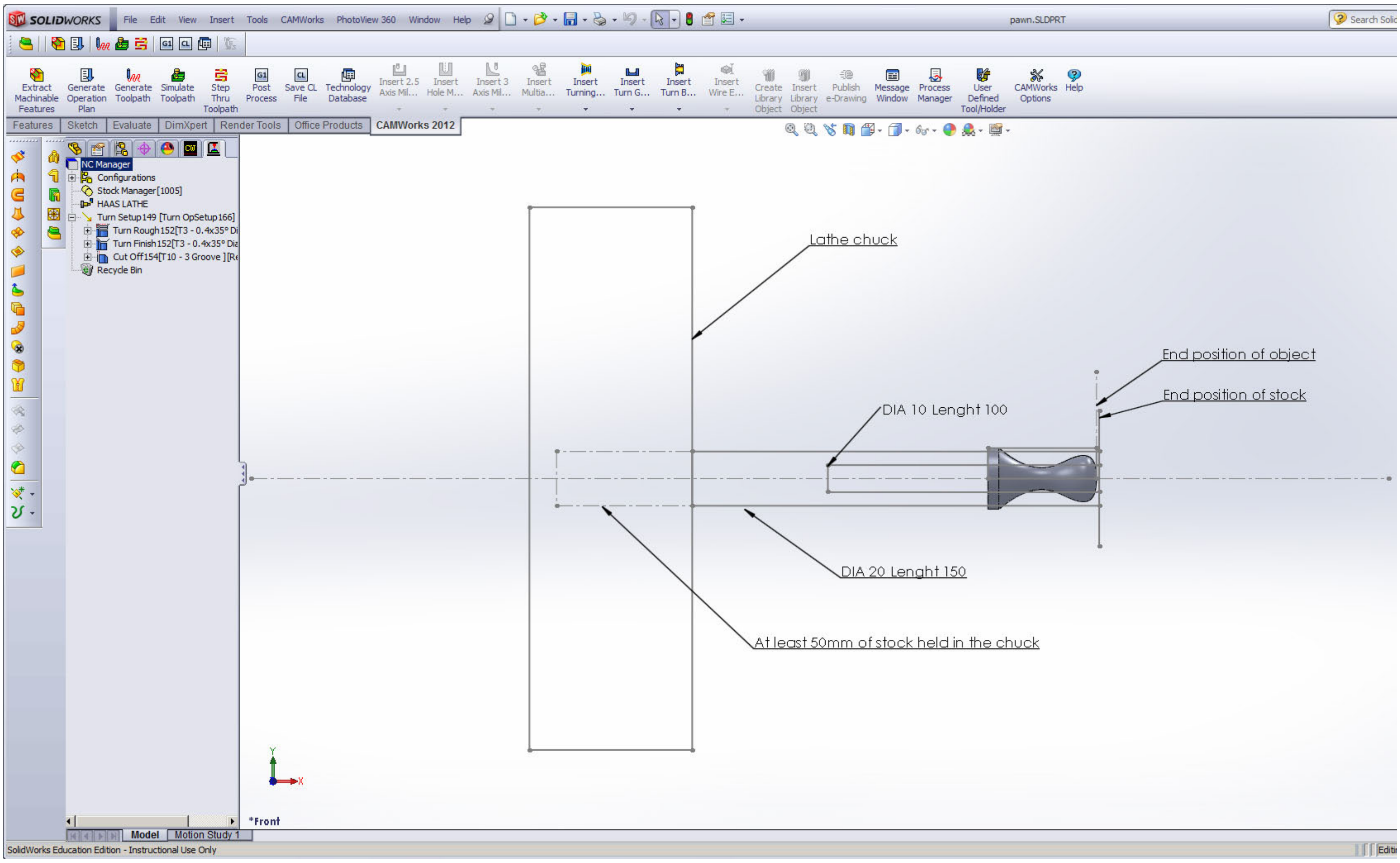
+ The revolution of the chuck is known as spindle speed (s), the revolutions per minute can be changed in the g-code or in the machine during a job according to the material in the lathe.

A spline is a polynomial curve, a series of points connected by lines to create a smooth curve, fewer points along the line give you a smoother surface, too many can create a curve that is is faceted. The facets are created from the CNC machine reading the spline as a series of straight lines between the points. Changing the size of the line that make up the spline lines increase how visible the line segments are that make up the curve. This is known as spline deviation, which could be called resolution similar to the pixilation of an image.

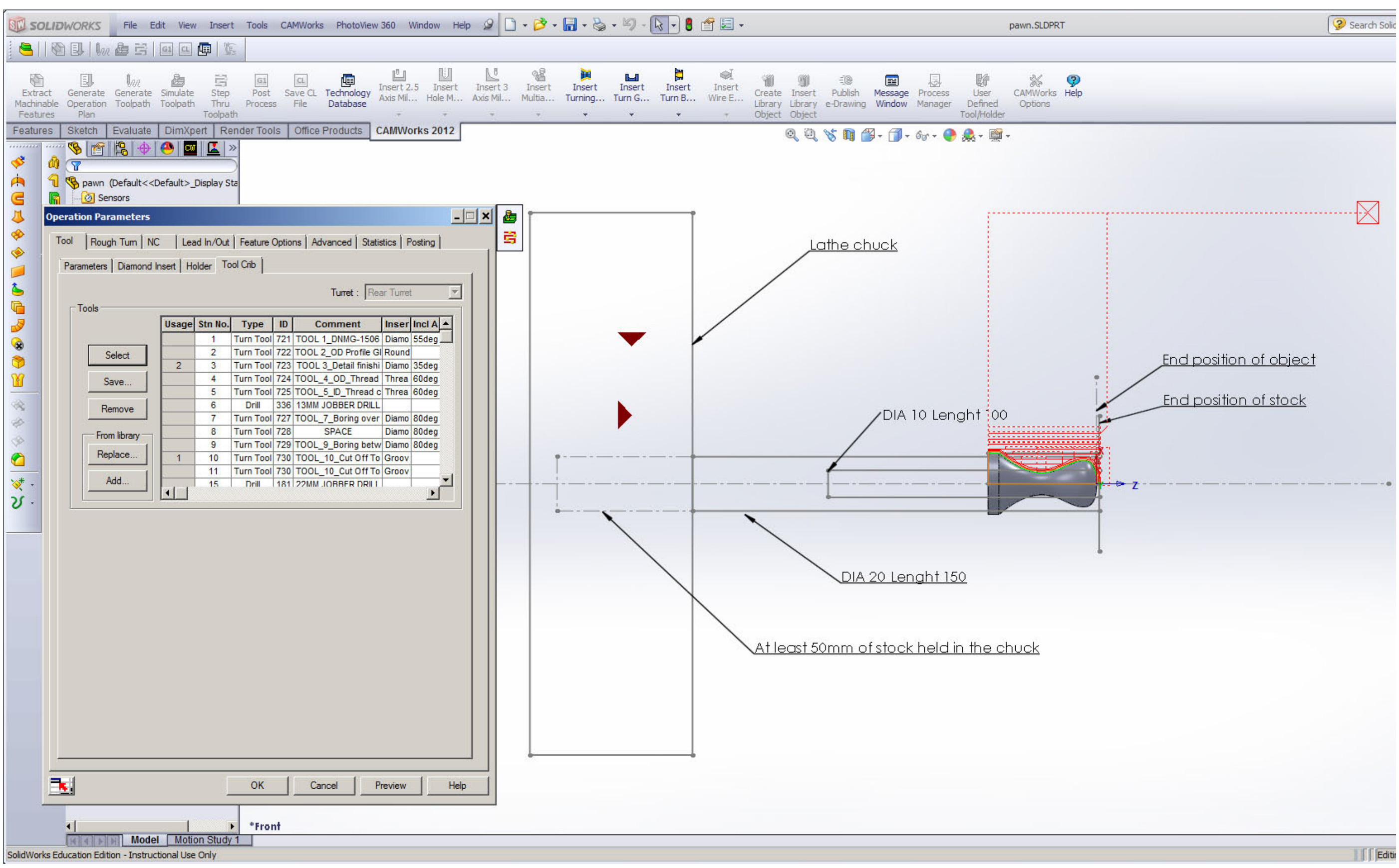
+ Changing the value of spline deviation at random numerical intervals to gauge the rate of change each form had a noticeable difference from machined precisely to a notably stepped curve that had some interesting visual qualities.

+ The drilling and boring operations performed showed an increase amount of vibration when keeping the material close to the chuck that was visibly different to the tools cutting on the outside profile.

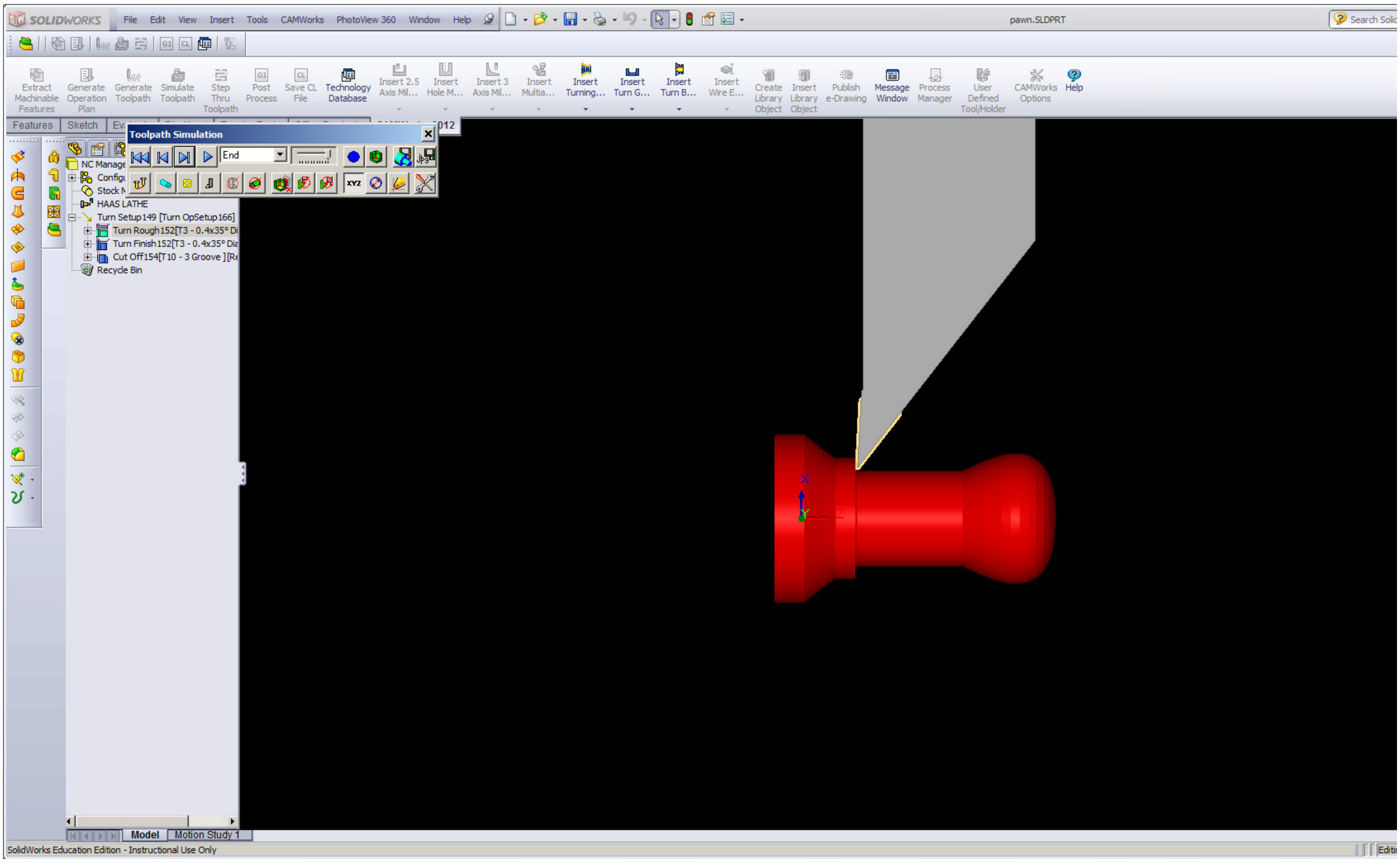
+ The parting tool which was slightly worn had some beautiful textures, looking similar to storm weather signatures. Investigating the results reported that there were immediately characteristics to start manipulating and gaining a level of control of with further testing.



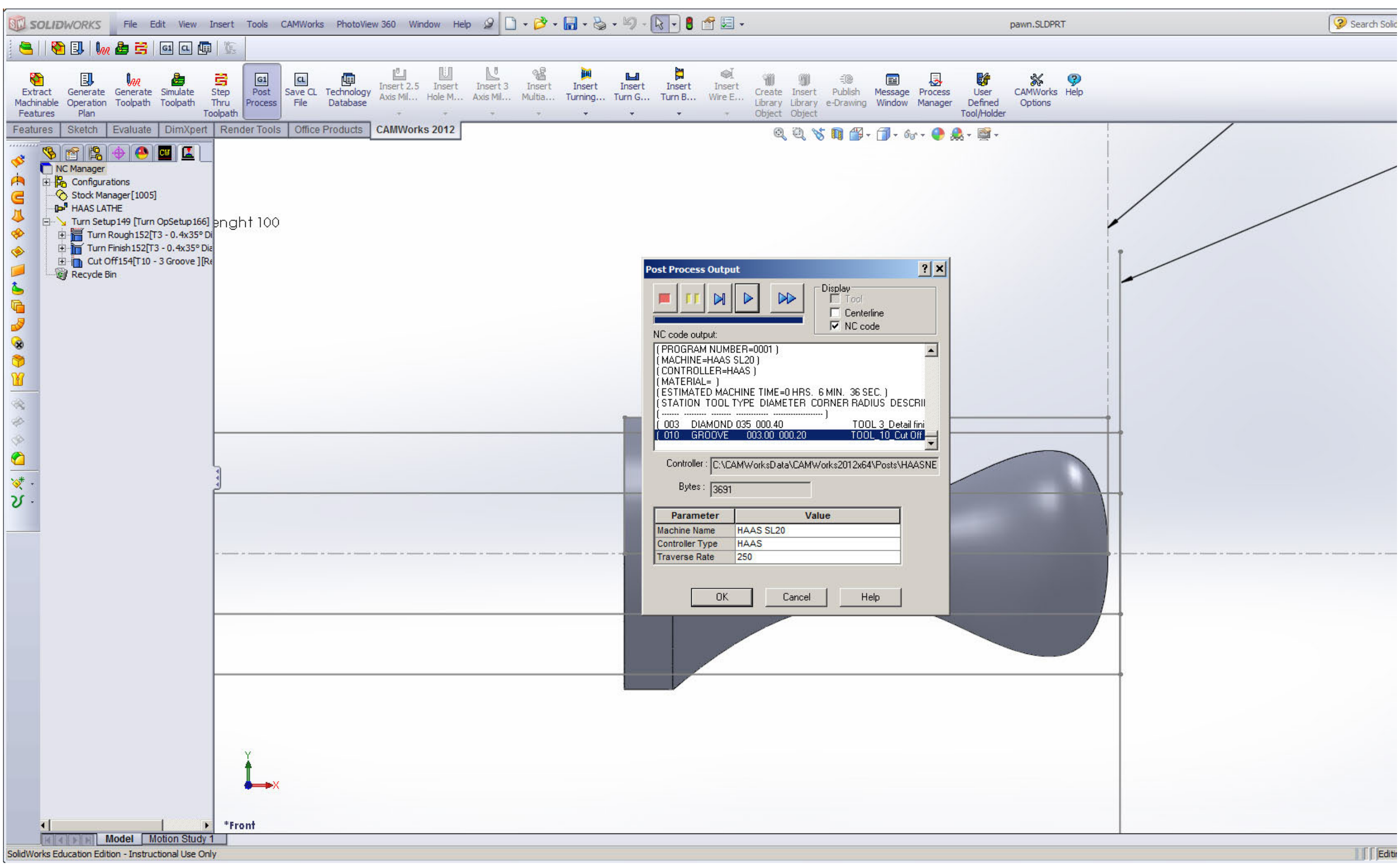
Creating a Profile on Solidworks using a Haas template complete with CAMWorks



Using the tool crib and looking at the simulated toolpaths to pick the right tool



Running through the simulation to check if everything runs correctly



Going through each step to finally output the G-Code

```
%
O0001
( PART NAME=pawn )
N1 G28 U0 W0
N2 (TOOL 2_OD Profile GIMY 525 ISCAR)
N3 G54 G40 T0202
N4 G50 S2000
N5 G99 G96 S200 M03
N6 G00 X200. Z3.54 M08
N7 X41.18
N8 G01 X36.1 Z1. F.1
N9 Z-42.5
N10 G00 X41.18
N11 Z1.
N12 X32.378
N13 G01 Z-42.5
N14 G00 X37.458
N15 Z1.

N117 X9.097 Z-22.068
N118 X9.135 Z-23.613
N119 X9.537 Z-25.144
N120 X10.284 Z-26.673
N121 X11.361 Z-28.204
N122 X12.748 Z-29.738
N123 X14.392 Z-31.244
N124 X17.967 Z-33.947
N125 X23.5 Z-37.461
N126 Z-42.5
N127 G00 X200.
N128 Z100.
N129 Z2.54
N130 X.107
N131 G01 X-4.973 Z0 F.05
N132 X-4.288 Z-.002
N133 X-3.589 Z-.008
N134 X-2.904 Z-.018
N135 X-2.232 Z-.031
N136 X-1.573 Z-.049
N137 X-.927 Z-.07
N138 X-.293 Z-.095
N139 X.329 Z-.125
N140 X.939 Z-.158
N141 X1.537 Z-.195
N142 X2.123 Z-.236
N143 X2.699 Z-.281
N144 X3.263 Z-.33
N145 X3.817 Z-.384
N146 X4.36 Z-.441
```

These outline the major parts in the code to look out for. (The N value only relates to the line numbder) In the beginning there is:

N4 G50 S2000| The name of the profile being turned the starting spindle speed.

N5 - N8 | (G99 G96 S200 M03) The path the turret is taking to the job.

N8 | (G01 X36.1 Z1.F1.) The feed rate it will be cutting at.

N9 | (Z-42.5) The distance of the job.

Once the rough passes come to an end it will read:

N117 - N126 | Closer to the dimensions from the CAD software

N127 - N131 | (G00 X200) Indicates the tool will retract and come back in for finishing cuts at a finer feed rate. (G01 X-4.973 Z0 F0.5)

N286 - N304 | Comes to the end of the finishing cut and returns the turret home to change over tools. (G28)

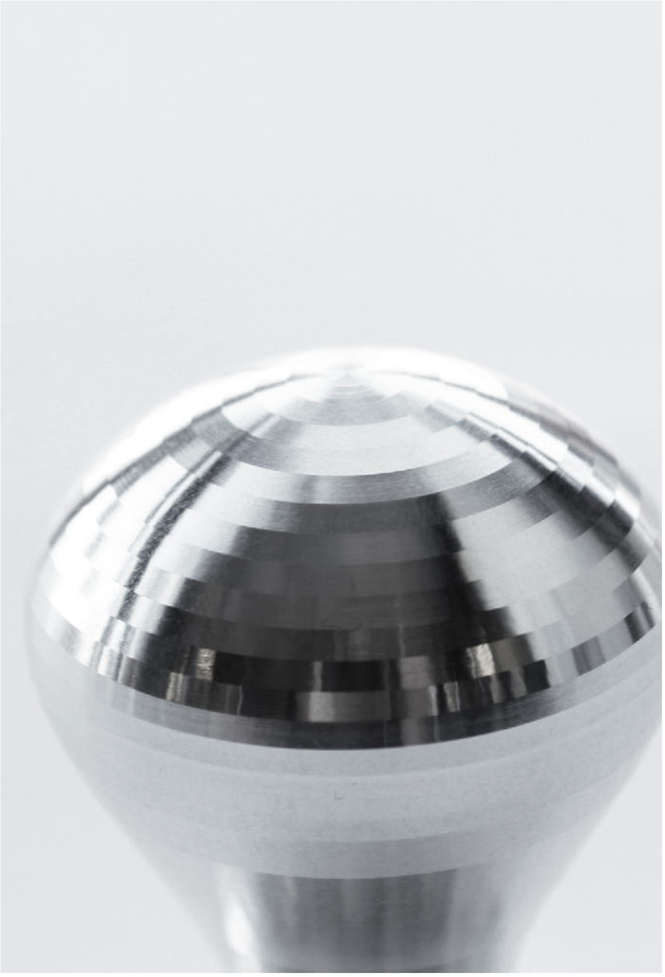
N306 - N307 | Signifies which tool is being used (G54 G40 T1010), the parting tool.

N308 - N313 | Is the cutting operation (X-2.4) takes the parting tool to the middle cutting it off from the stock and cleaning up the end.

N314 - N320 | (G28 U0 W0) Returns the turret home and completes the job cycle, logging how long the machining took.

```
N286 X14.611 Z-32.384
N287 X14.98 Z-32.67
N288 X15.332 Z-32.937
N289 X15.669 Z-33.188
N290 X15.99 Z-33.422
N291 X16.29 Z-33.638
N292 X16.88 Z-34.053
N293 X17.402 Z-34.411
N294 X17.868 Z-34.724
N295 X18.282 Z-34.997
N296 X18.644 Z-35.233
N297 X19.302 Z-35.652
N298 X19.794 Z-35.96
N299 X20.555 Z-36.428
N300 X22.5 Z-37.595
N301 Z-42.5
N302 G00 X200.
N303 Z100.
N304 G28 U0 W0
N305 M01


N306 (TOOL_10_Cut Off Tool 150.10-3N-14)
N307 G54 G40 T1010
N308 G50 S2000
N309 G99 G96 S150 M03
N310 G00 X200. Z-40.46 M08
N311 X47.98
N312 G01 Z-43. F.05
N313 X-2.4
N314 G00 X62.5
N315 X200.
N316 Z100.
N317 G28 U0 W0
N318 M05
N319 M09
N320 M30
%
( PART NAME=pawn )
( PROGRAM NUMBER=0001 )
( MACHINE=HAAS SL20 )
( CONTROLLER=HAAS )
( MATERIAL=  )
( ESTIMATED MACHINE TIME=0 HRS.  6 MIN.  49 SEC. )
( STATION  TOOL TYPE  DIAMETER  CORNER RADIUS  DESCRIPTION              )
( -------  ---------  --------  -------------  -------------------- )
(  002     ROUND   080  002.50                         TOOL 2_OD Profile GIMY 525 ISCAR)
(  010     GROOVE       003.00  000.20                 TOOL_10_Cut Off Tool 150.10-3N-14)
```



Spline Deviation over profile

Light Refractions off form

150mm protruding from chuck, Vibrations

Macro of Vibrations and Spline deviation

Clean Finish Tamper

Worn Tool rough texture

Tactility of Wearing

Parting off tool marks

Change in markings

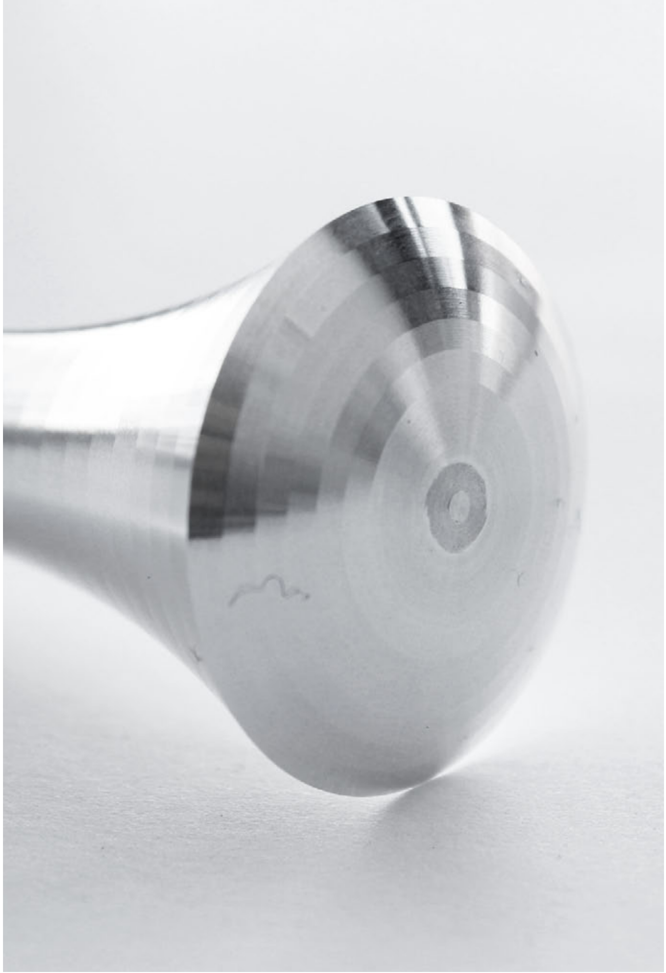
Images pixelated on the deviations

Boring bar Vibrations

Spline Deviation fade

Linear Forms testing accuracy

Stepping on a Shallow Dome



Tool Wear at the Apex

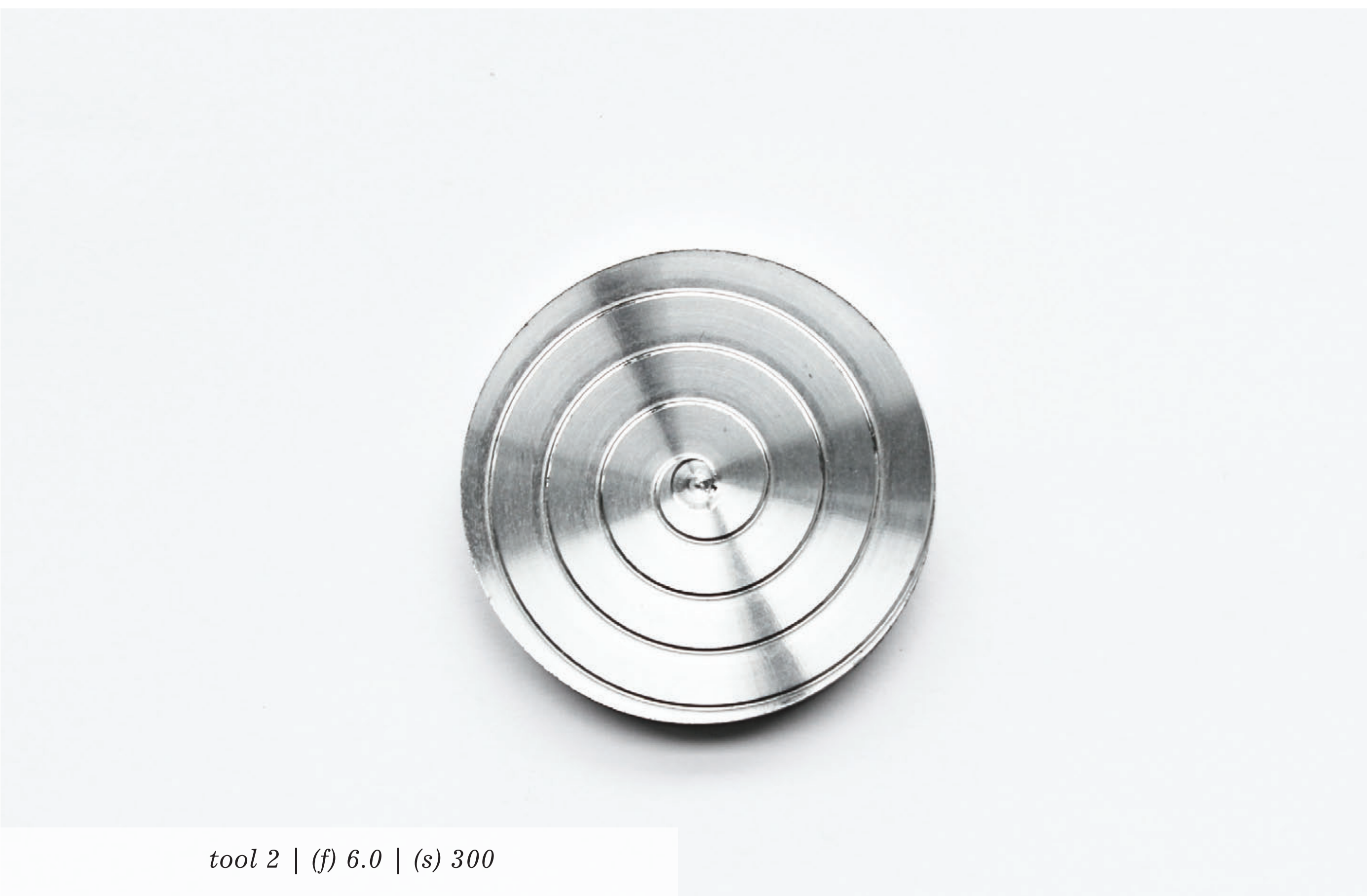
First Series

SECOND SERIES

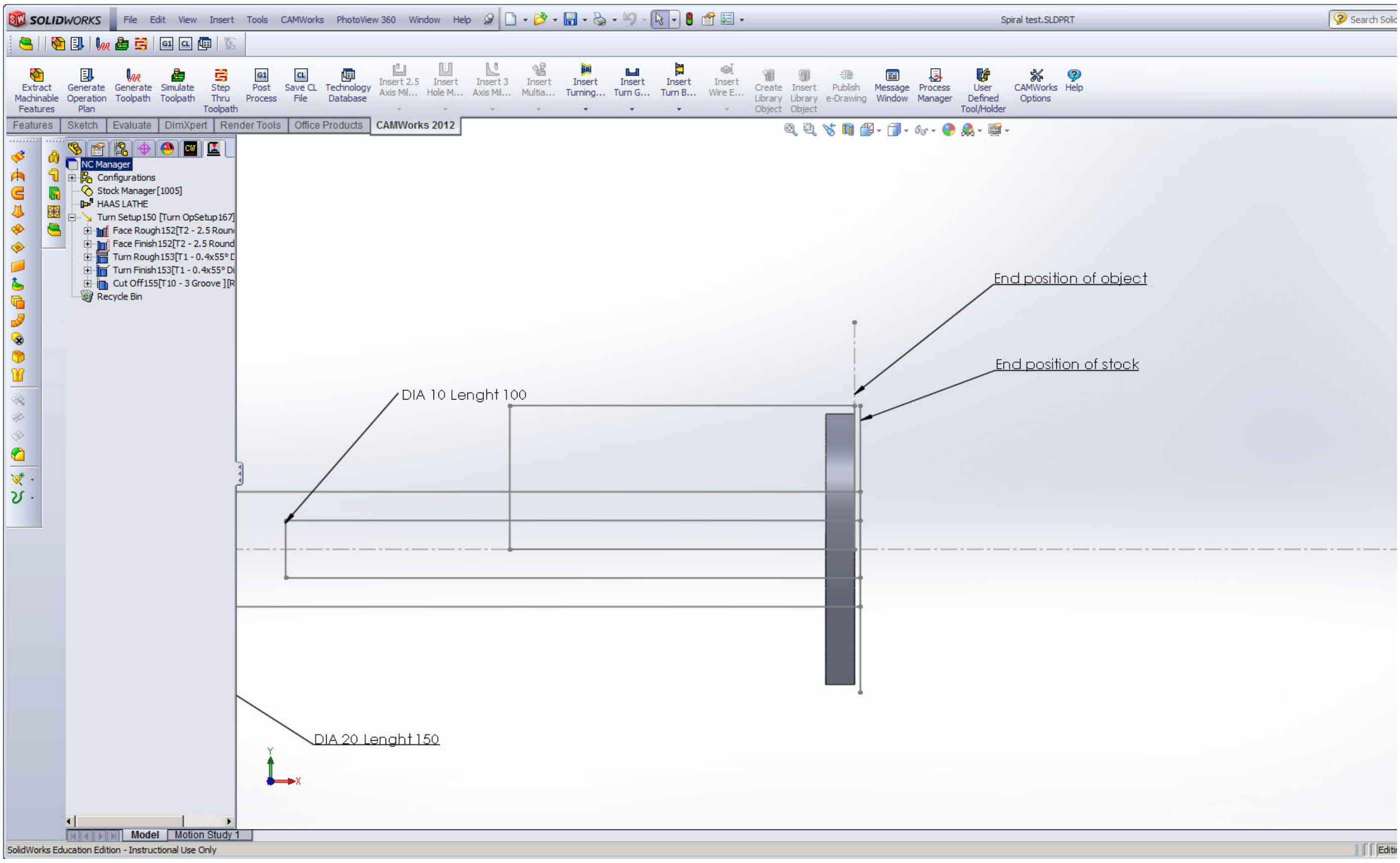
The second series replicates an interesting effect found by Tim Miller when the CNC lathe first came into the university. This was 4 years ago so the samples had to be created again to make record a of the result and the numerical changes in the code. The effect was spirals on the face of a material; the spirals were produced through changing the feed rate, (f) value, and spindle speed, (s) value, so that the tool would go in at different depths and slower speeds. This instruction was performed on the finishing cut with 3 small 0.1mm cuts passing over the job; this was a safety precaution so that any tool I used would not break under stress. At first the first tip in tool 2 was used which had the radius at the bottom and straight edges, this showed bigger gaps in the spirals with higher peaks. The alternative tool 2 with a radius all-round the end of tool created a smoother spiral with a nice clean finish on the end product. Tool 3 was interesting as the sharpness of the tool made a flat spiral that tapered in towards the centre. Every numerical change I made to the code demonstrated a unique spiral each time and recording those changed allowed me to start to correlate what was going to happen and relate the (f) value with the (s) value.

tool 2 | (f) 6.0 | (s) 300

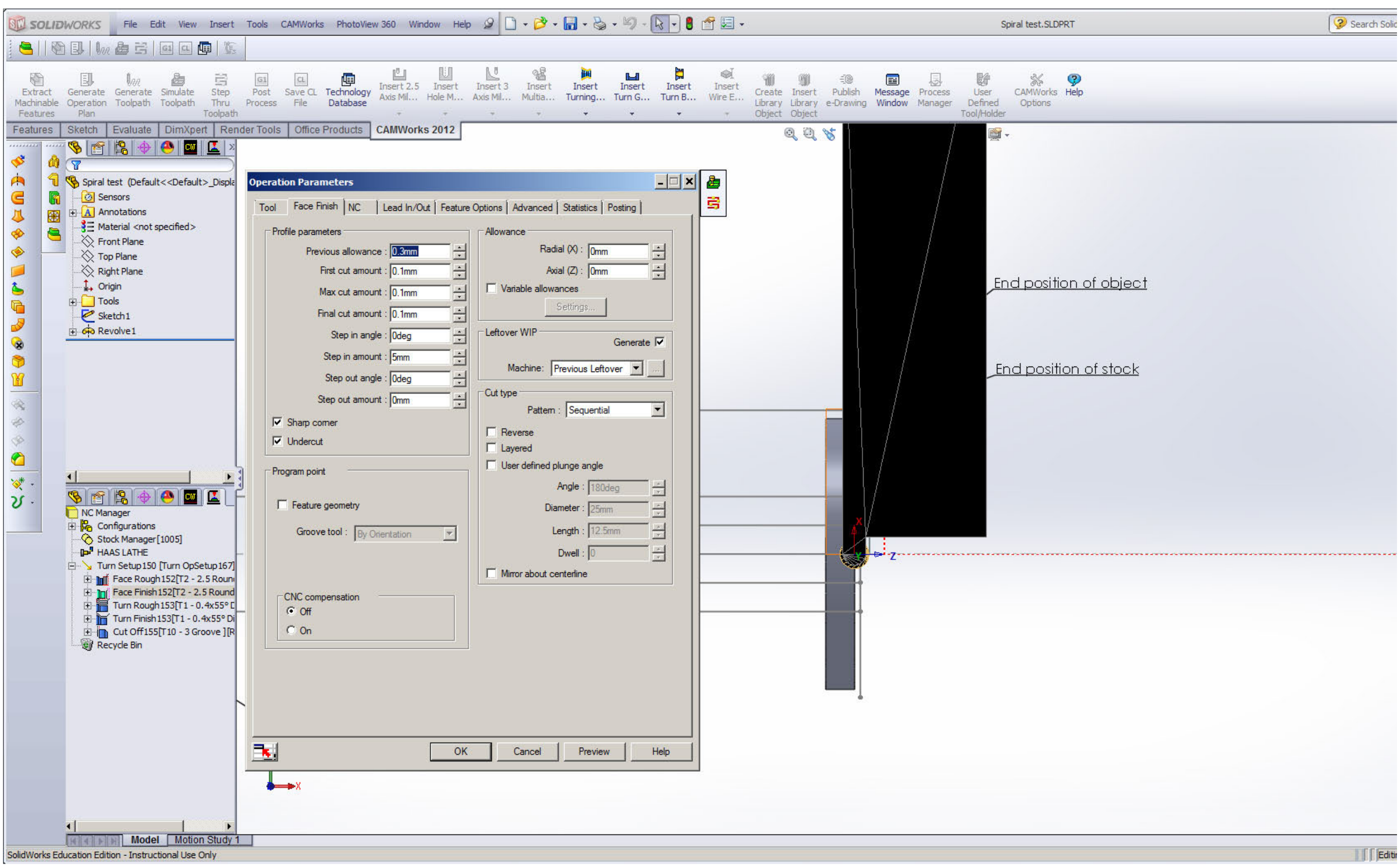
tool 2 | (f) 6.0 | (s) 300



tool 2 | (f) 6.0 | (s) 300



Creating the profile in SolidWorks for face spirals



Changing the allowance to 0.3mm and following cuts to 0.1mm so that the cutting tool passes 3 short cuts

```
%
O0001
( PART NAME=2Frontfacefinish )
N1 G28 U0 W0
N2 (TOOL 2_OD Profile GIMY 525 ISCAR)
N3 G54 G40 T0202
N4 G50 S480
N5 G99 G96 S480 M03
N6 G00 X200. Z2.94 M08
N7 X55.08
N8 X50. Z.2
N9 G01 X-5. F12.
N10 G00 Z2.94
N11 X50.
N12 Z.2
N13 G01 X-5.
N14 G00 Z2.84
N15 X50.
N16 Z.2
N17 G01 X-5.
N18 G00 Z2.74
N19 X50.
N20 Z.2
N21 G01 X-5.
N22 G00 Z2.64
N23 X50.
N24 Z.2
N25 G01 X-5.
N26 G00 Z100.
N27 X200.
N28 G28 U0 W0
N29 M05
N30 M09
N31 M30
%
( PART NAME=2Frontfacefinish )
( PROGRAM NUMBER=0001 )
( MACHINE=HAAS SL20 )
( CONTROLLER=HAAS )
( MATERIAL=  )
( ESTIMATED MACHINE TIME=0 HRS.  0 MIN.  34 SEC. )
( STATION  TOOL TYPE  DIAMETER  CORNER RADIUS  DESCRIPTION              )
( -------  ---------  --------  -------------  -------------------- )
(  002     ROUND   080  002.50                        TOOL 2_OD Profile GIMY 525 ISCAR)
```

Spiral Test Code

In this short piece of code it highlights the major difference when creating the spiral:

N4 | Showing that the spindle speed is down to 480rpm

N9 | The feed rate is now (F12.) providing a deeper cut at slower speeds

N10 - N13 | Is that start of the three 0.1mm cuts into the face profile ending at N26 at which point the turret retracts.

tool 2 | (f) 6.0 | (s) 300

tool 2 | (f) 6.0 | (s) 450

tool 2 | (f) 6.0 | (s) 600

tool 2 | (f) 4.0 | (s) 600

tool 2 | (f) 8.0 | (s) 600

tool 2 | (f) 10.0 | (s) 600

tool 2 | (f) 12.0 | (s) 600

tool 2 | (f) 12.0 | (s) 450

THIRD SERIES

The third series expanded on the last two but provided more complex forms, designed chess pieces, rings and pyramids looking at using a larger range of materials like nylatron, acetol and ertalon.

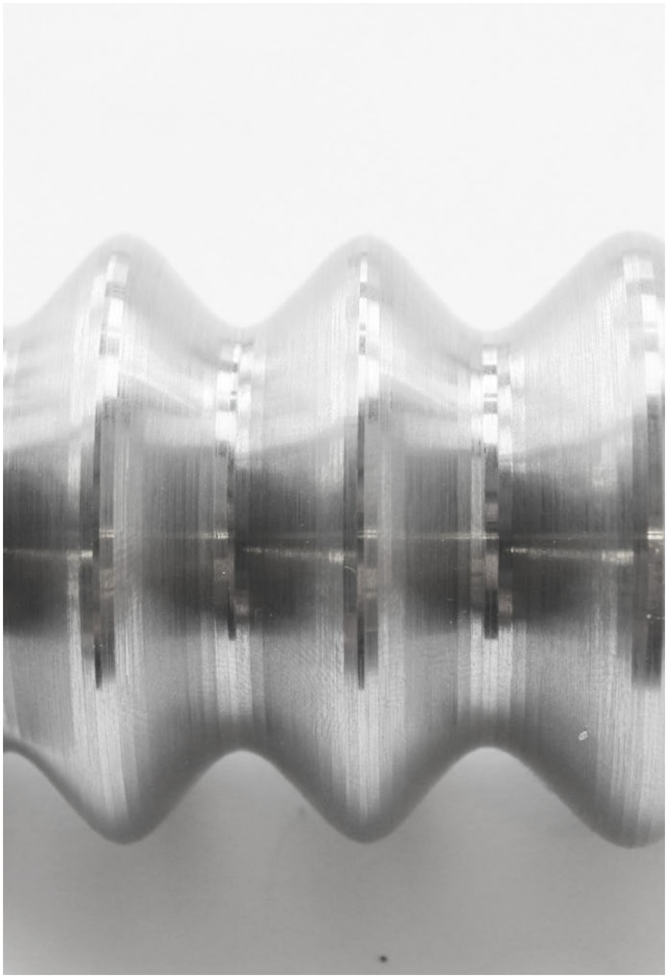
+ Better insight choosing to do more values at smaller intervals to see what each experiment would show.

+ Doing the same spline deviation test with boring operations brought about vibration on the internal passes.

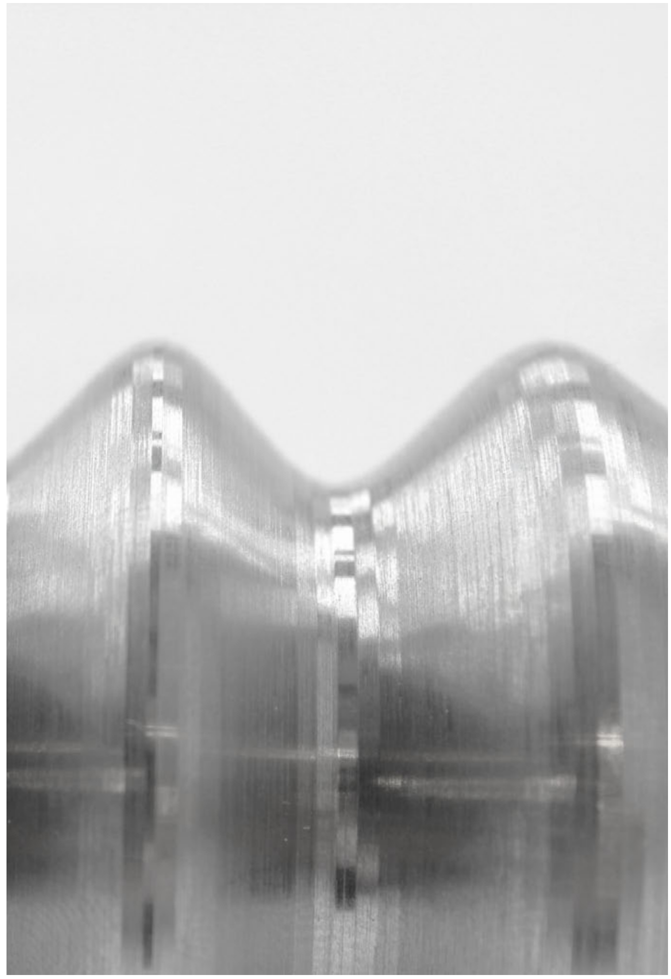
+ Grooving on a couple form samples showed that using the rounded tool 2 on a shallow groove and the parting tool on deeper grooves gave the same result creating quite pronounced tooling marks.

+ Using the plastics was interesting finding out the correct speeds to use so that they wouldn't melt, the colours and ease with which these plastics machine make them a very attractive material to use.

+ An initial trial was conducted to see how thin this material could be turned before there was structural failure, 1mm being the comfortable known thickness for John to go, taking it down to 0.8mm and seeing signs of some flexibility adding vibration effects. There wasn't any signs of the material buckling so there is potential to go even thinner in the experiments.



Mild Steel Complex Deviation

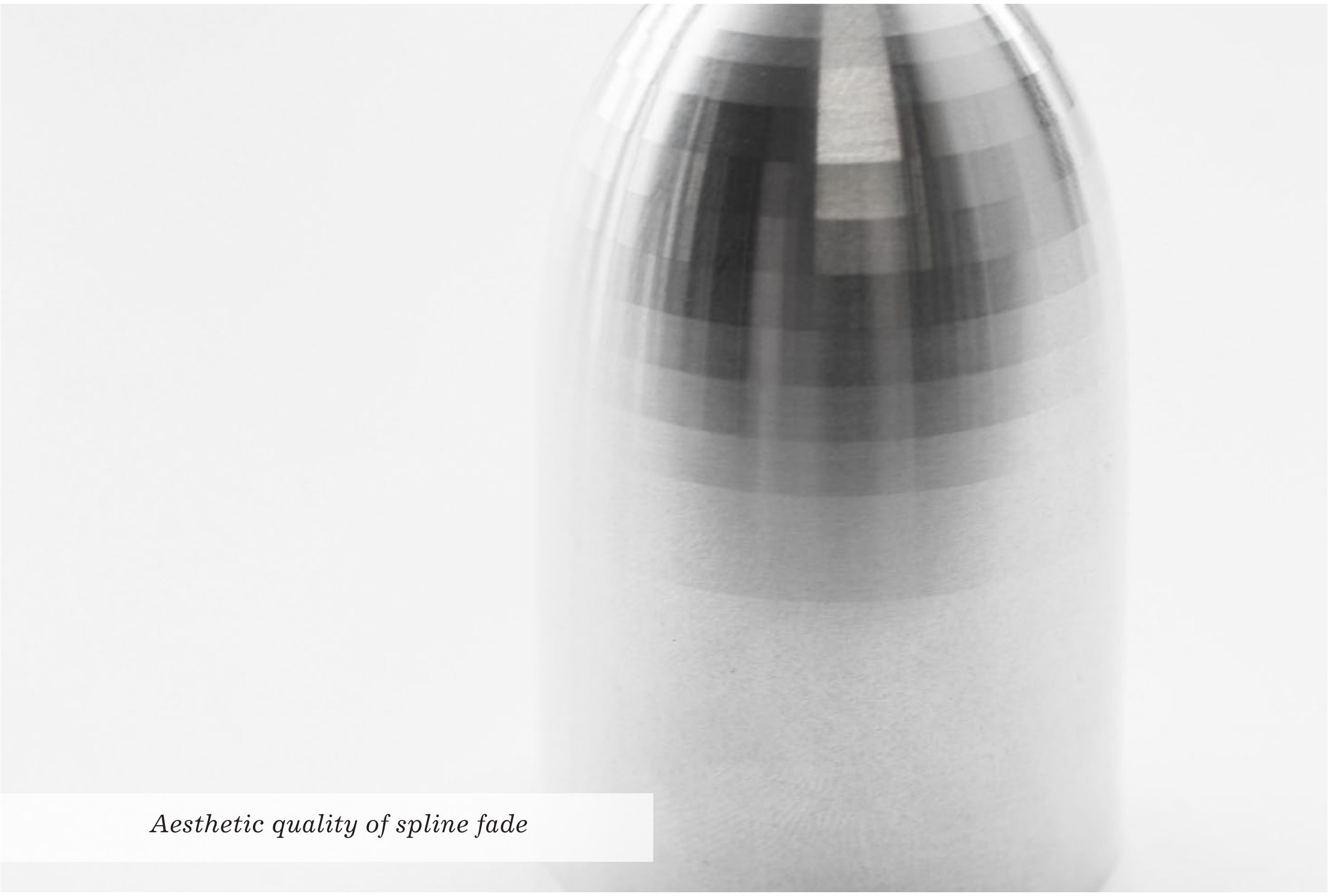


Close up on Areas of deviation

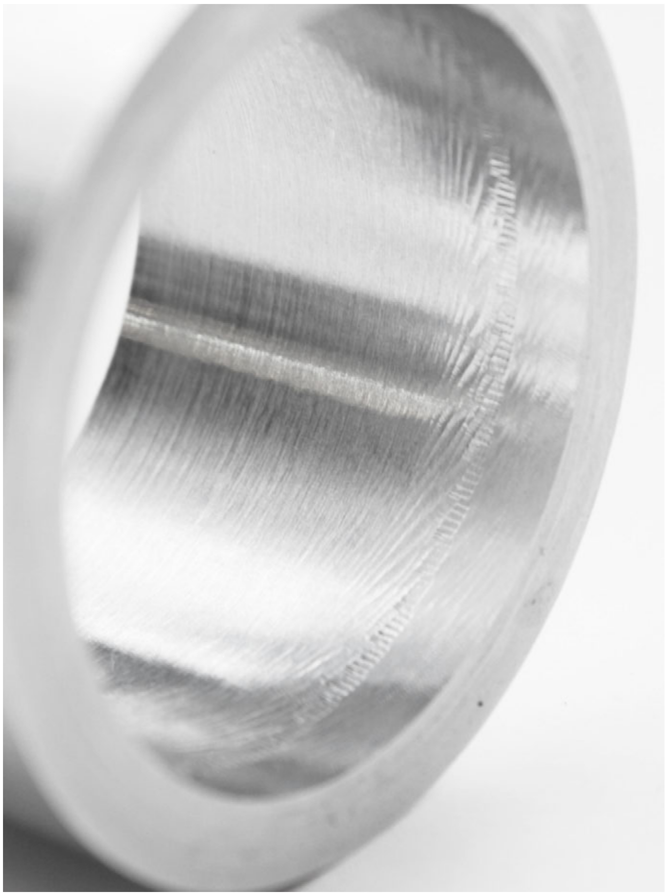
Chess piece (Queen) Crown

Curved profile rings with spline lines

Vibration at widest diameter

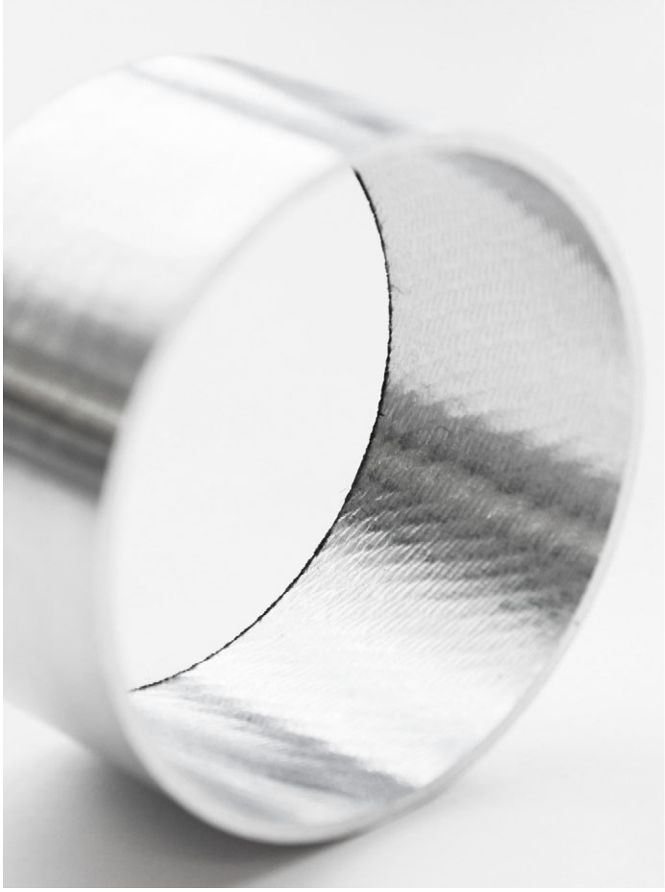


Aesthetic quality of spline fade

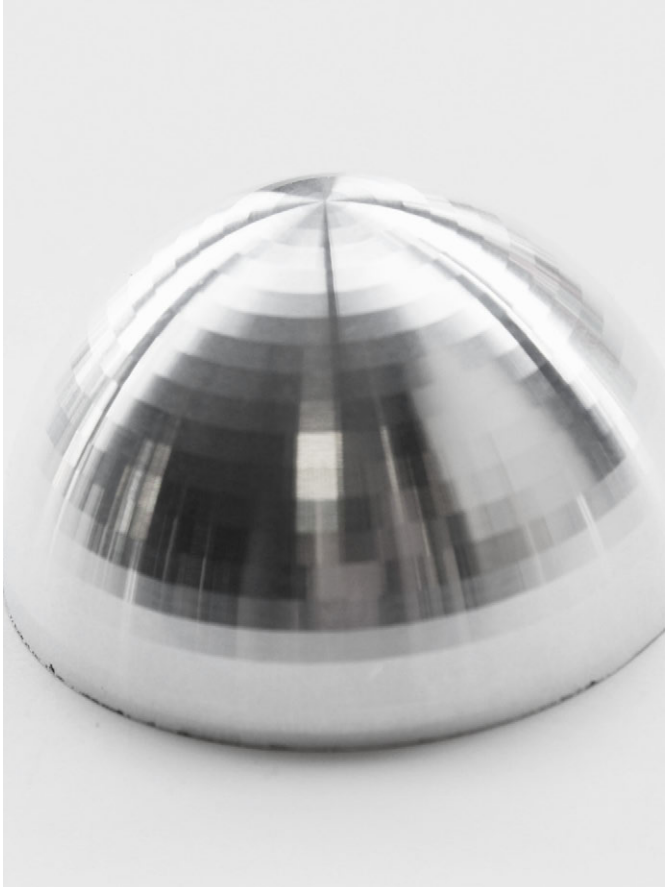


Boring Vibration on a thick wall

Boring vibration on a thin wall



Beautiful patterns and reflections



Hollow Dome

Internal vibration and deviation

Drilling and Boring limitations

Grooving test with tool 2

Grooving marks

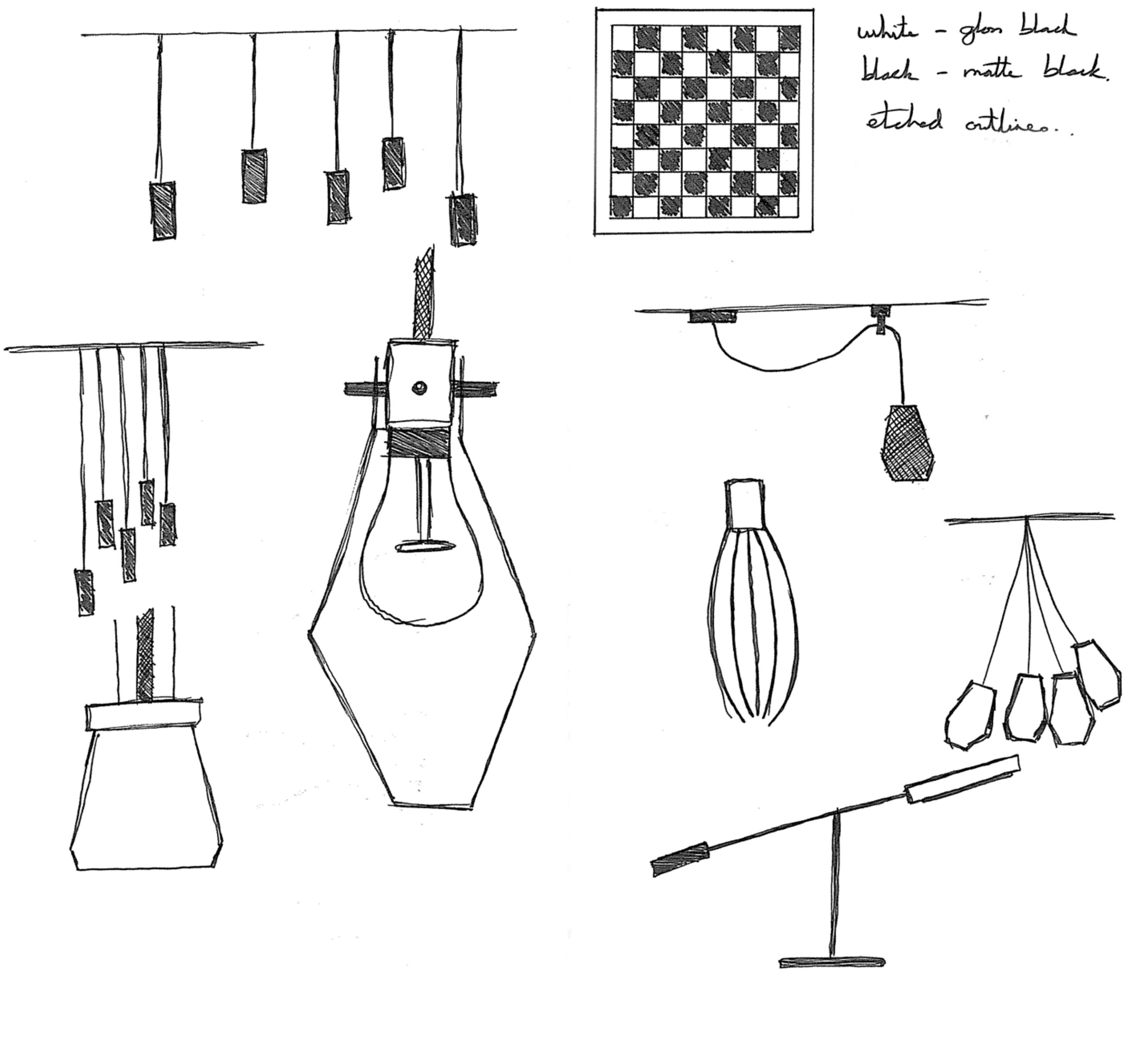
7

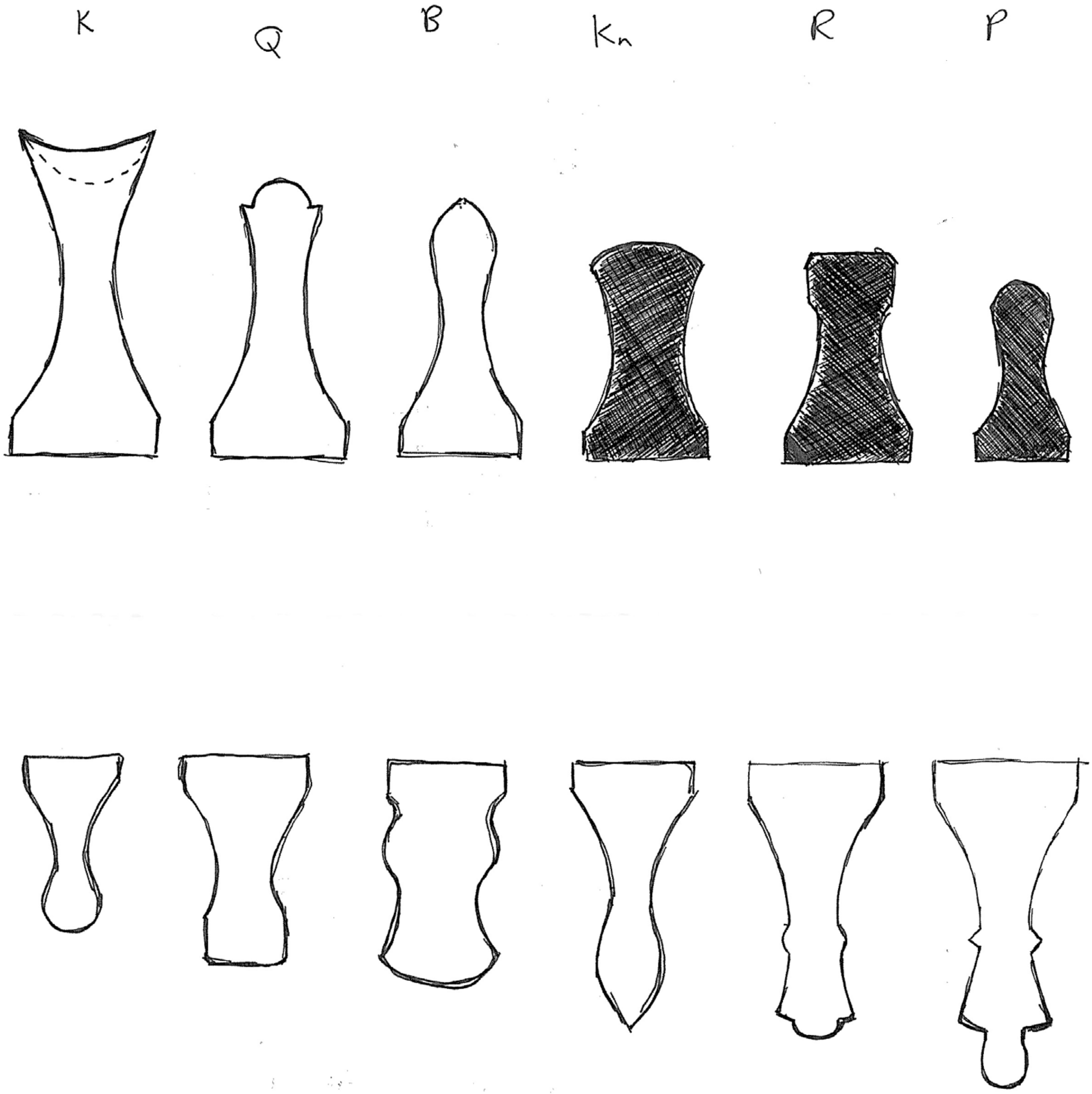
developed design

serendipitous collection

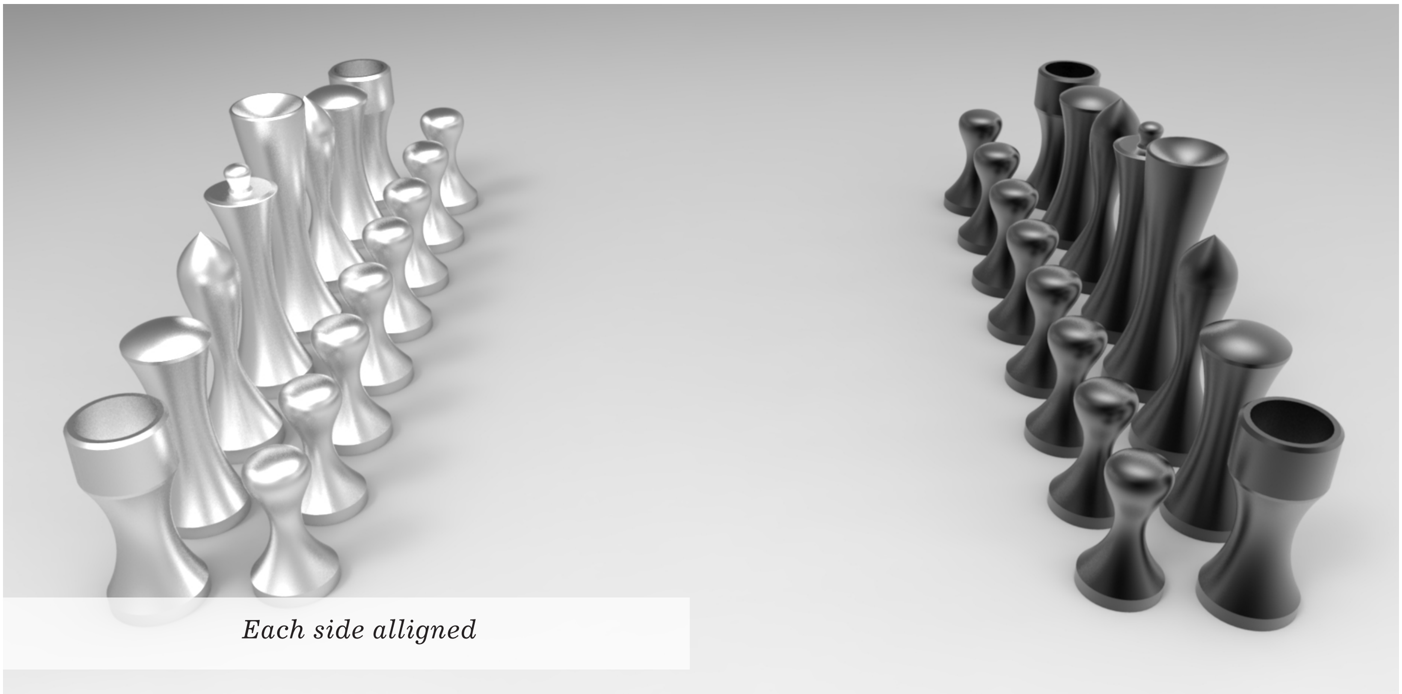
FOURTH SERIES

After the spiral study, a design was needed to showcase patterns and also act as a deadline to keep progress going forward. A chess set was designed to explore these results, looking into the tradition of craft associated with it and the relationship of turning pieces as a primary means of manufacture. It has a long history with craftmanship and the people that have made them show a great level of skill creating the pieces often becoming centre pieces displayed in the house. The opposing sets were designed to create the narrative of the precision machined side (white set) against the surface textures expressed on the mirrored side (black set), making them all individual. The production was manufactured in a couple days machining the pieces in aluminium so that a polished high quality finish could be achieved andcompleted with a felt bottom to pay homage to the traditional chess set. The board was made from acrylic using the laser cutter to make the shapes and the templates so it could be sandblasted to make traditional white squares matte black and the alternate glossy black. The composition together was well received at Bo Concept and Raglan Roast, with many people looking at the pieces in detail and playing a few games over a coffee. This process was a great test into expressing the spiral pattern over a complex 3 dimensional form and choosing the right tool for the piece on the board.


white - gloss black
black - matte black.
etched outlines..


K
Q
B
Kn
R
P

CAD model chess pieces



Each side alligned

```
N211 G01 X-4.754 Z.197 F4.5
N212 X.512 Z.077
N213 X6.012 Z-.347
N214 X11.316 Z-1.129
N215 X14.049 Z-1.714
N216 X16.618 Z-2.401
N217 X19.093 Z-3.216
N218 X23.33 Z-4.924
N219 X23.159 Z-7.927
N220 X19.466 Z-13.334
N221 X16.889 Z-18.275
N222 X15.916 Z-20.703
N223 X15.132 Z-23.153
N224 X14.546 Z-25.601
N225 X14.158 Z-28.047
N226 X13.967 Z-30.492
N227 X13.975 Z-32.936
N228 X14.18 Z-35.38
N229 X14.582 Z-37.824
N230 X15.183 Z-40.269
N231 X15.981 Z-42.715
N232 X16.968 Z-45.138
N233 X19.581 Z-50.078
N234 X22.045 Z-53.75
N235 X25.4 Z-57.985
N236 Z-62.5
```

```
N237 G00 X30.48
N238 Z.097
N239 X-4.763
N240 G01 X.492 Z-.023
N241 X5.968 Z-.445
N242 X11.248 Z-1.224
N243 X13.962 Z-1.804
N244 X16.515 Z-2.487
N245 X18.975 Z-3.297
N246 X23.127 Z-4.971
N247 X22.96 Z-7.909
N248 X19.275 Z-13.305
N249 X16.694 Z-18.252
N250 X15.719 Z-20.685
N251 X14.933 Z-23.139
N252 X14.347 Z-25.591
N253 X13.958 Z-28.041
N254 X13.767 Z-30.49
N255 X13.775 Z-32.938
N256 X13.98 Z-35.386
N257 X14.383 Z-37.834
N258 X14.985 Z-40.283
N259 X15.785 Z-42.733
N260 X16.774 Z-45.161
N261 X19.39 Z-50.107
N262 X21.857 Z-53.784
N263 X25.2 Z-58.004
N264 Z-62.5
```

```
N265 G00 X30.28
N296 M01 N267 X-4.772
N268 G01 X.472 Z-.122
N269 X5.924 Z-.543
N270 X11.181 Z-1.318
N271 X13.875 Z-1.894
N272 X16.413 Z-2.573
N273 X18.857 Z-3.378
N274 X22.925 Z-5.018
N275 X22.76 Z-7.891
N276 X19.083 Z-13.276
N277 X16.499 Z-18.23
N278 X15.522 Z-20.667
N279 X14.735 Z-23.125
N280 X14.148 Z-25.581
N281 X13.758 Z-28.035
N282 X13.567 Z-30.488
N283 X13.575 Z-32.94
N284 X13.78 Z-35.392
N285 X14.184 Z-37.844
N286 X14.787 Z-40.297
N287 X15.588 Z-42.751
N288 X16.579 Z-45.183
N289 X19.198 Z-50.135
N290 X21.669 Z-53.819
N291 X25. Z-58.023
N292 Z-62.5
N293 G00 X200.
N294 Z100.
N295 G28 U0 W0
N296 M01
```

The difference in the 3 dimensional spiral is that the passes over the profile are on the finishing passes after the bulk of the profile has been formed using the correct tool to cut the spirals.

N211 | (G01 X-4.754 Z.197 F4.5) Shows where you change the feed rate (F4.5) to create deeper cuts. The value can change according the spiral that is wanted. The speed rate is altered through the control panel of the machine.

N212 - N236 | Displays the tooling path taken over the profile in the first pass. A quick split second movement.

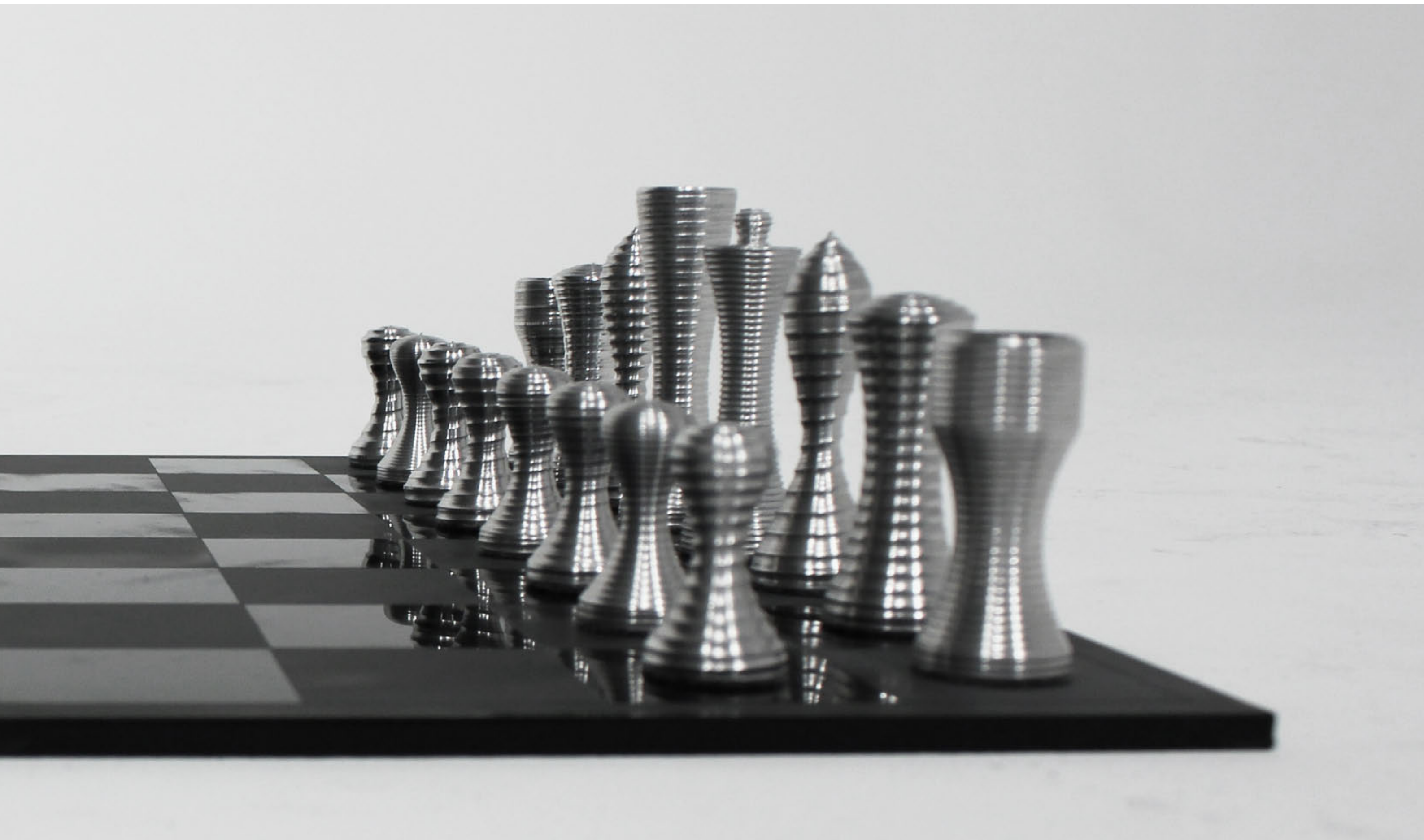
N237 - N264 | Again the tools retracts and repeats the pass for a second time.

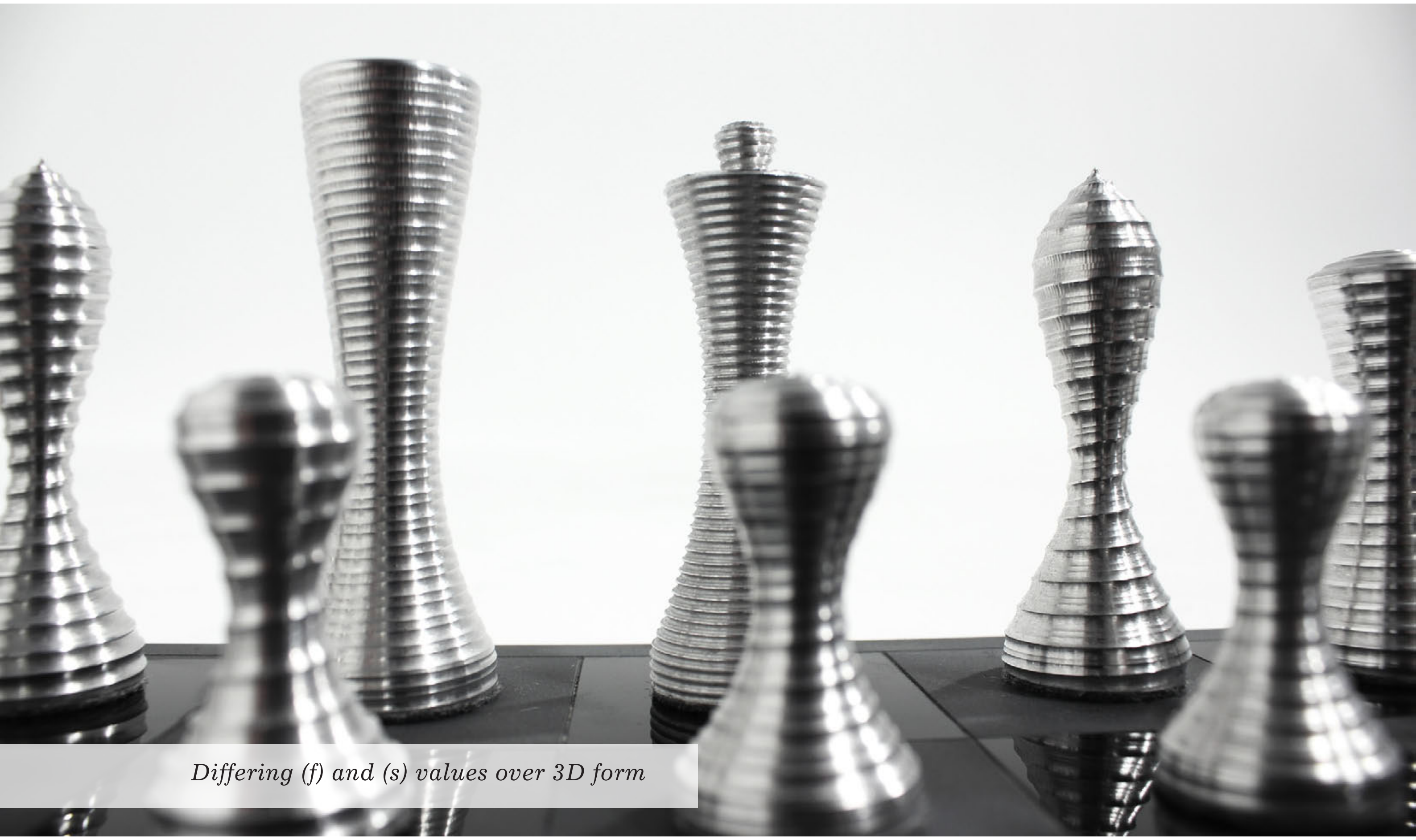
N265 - N296 | The third pass goes over the job and the turret moves away from the job to the home position to change tools.

These passes happen very quick and with the revolution of the chuck there can be a change in how many spirals are formed.

Full Chess set and Board, Clean vs Altered

Close up of the opposing sides



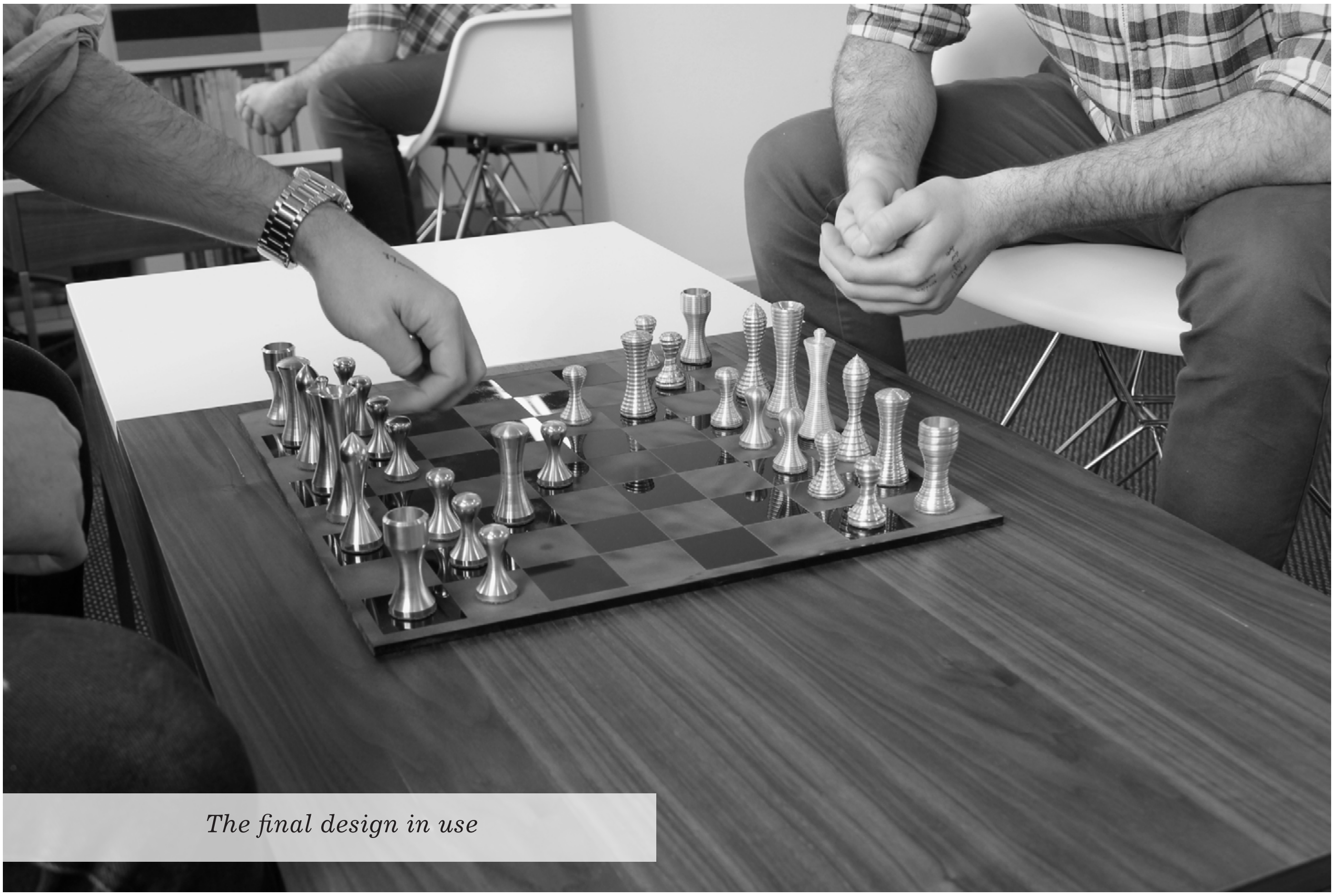


Differing (f) and (s) values over 3D form

Macro Detail of the Bishop

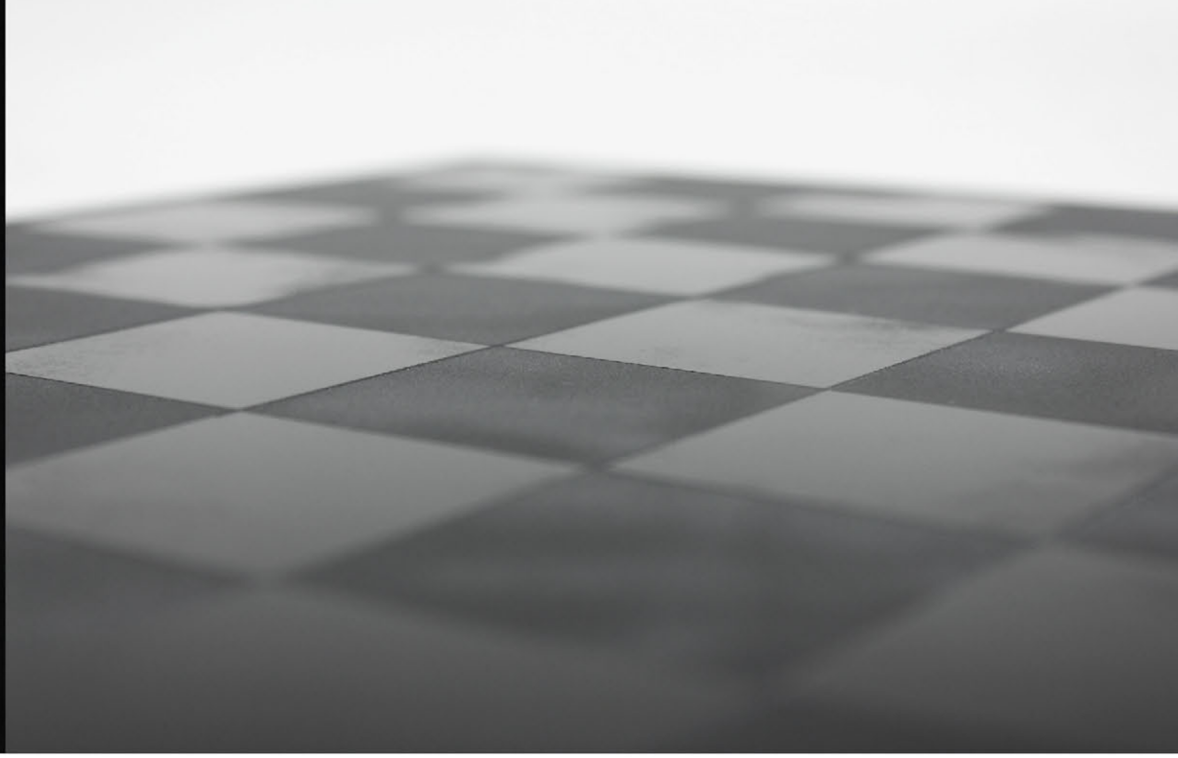
Aluminium set with Acrylic

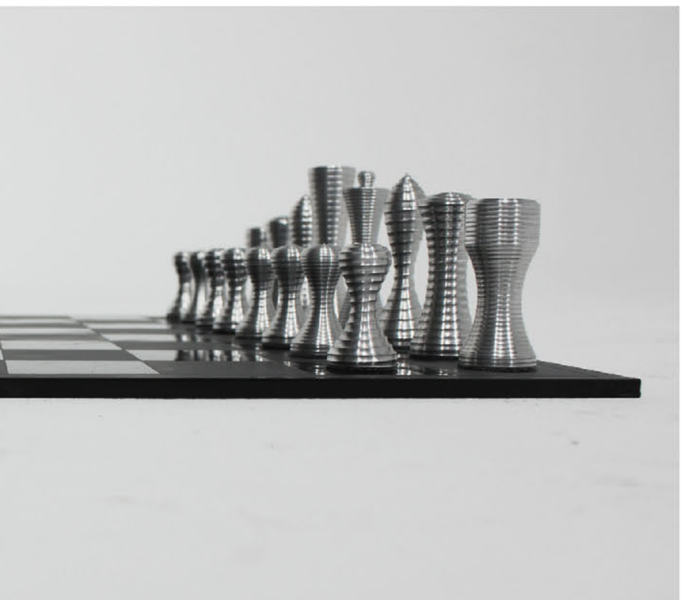
Rook, Knight, Bishop and Pawn



The final design in use

serendipitous collection





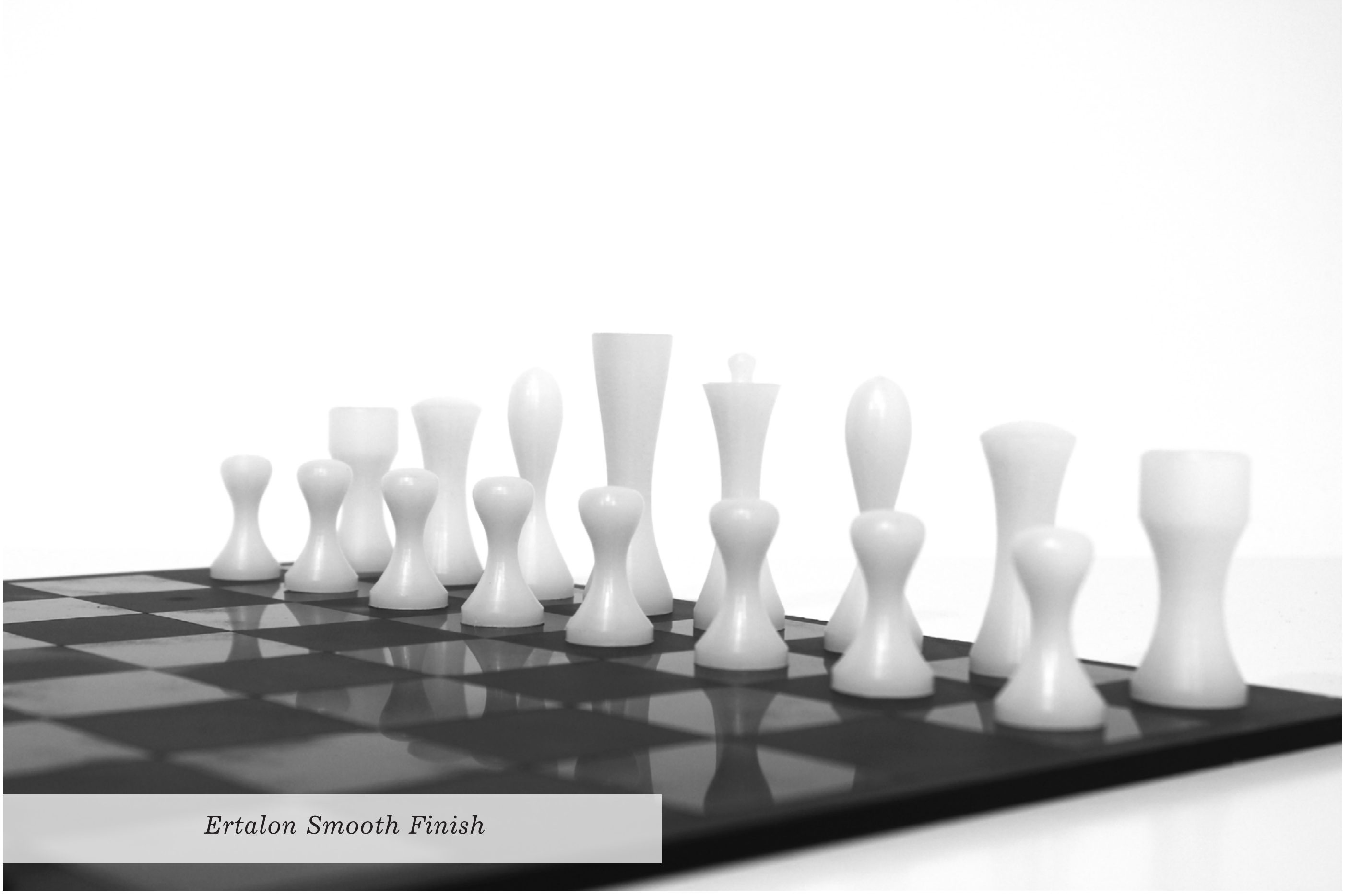
FIFTH SERIES

The next part in this design phase was making the chess set out of ertalon and nylatron applying what was learnt previously with these two materials. The pieces that came out irregular were from turning too fast and the material melting as soon as it came off the stock and attaching back to the form being made. The extreme version of this left the swarf clustered up on the chess piece and the mild version left a gritty texture on the surface. The swarf coming off tells a story with the Ertalon coming off in solid twirls meaning the material is quite dense in its manufacture and a little more difficult to machine and the Nylatron coming off in translucent slithers machining smoothly and cutting freely.

Swarf is the common name for the shavings that come from machining a material. It can come from metals, woods, stone or plastics in different forms. Grinding metals, wood and stone coming off in little chips or sawdust while tough metals and plastics producing long tendrils. Swarf can give a good indication of how the material performs, the heat it generates and how the machine is cutting.

Swarf melting back onto the piece

Nylatron (black) and Ertalon (White)



Ertalon Smooth Finish

Nylatron Pattern

SIXTH SERIES

The sixth series had more assertive testing looking at previous experiments and figuring out the logistics behind how they worked as well as gaining confidence in the strength and resilience of the machine to be able to abuse and misuse it. Using stainless steel, copper and scrap metals I turned profiles that would test the materials turnability and show the serendipitous flaws of the scrap metal:

+ An organic form revealed that through weathering the scrap material had inconsistent wall thicknesses so when turning there were splits on an outside surface showing cleanly machined metal and leaving some clear signs of the age of the steel.

+ On some of the smaller diameter stock the form turned out of control in areas tearing the material.

+ Grooving on stainless steel over an entire profile and using the tougher turning material decorated it with a spiral start each time the tool went in to perform the groove on a quarter turn.

+ The copper was mostly scrap and it was machine to clean it away and see the effect of the tooling and how it would react being used.

+ Abusing the machine came in the form of using mild steel and turning a profile with differing diameters and then passing through again cutting 5mm to 10mm off at a time at increasing spindle speeds start from 800rpm going up to 2000rpm eventually deciding to turn off the coolant.

+ Depending on the profile, the job would heat up to great temperatures sometimes visible on the finished object and clearly evident on the swarf coming off.

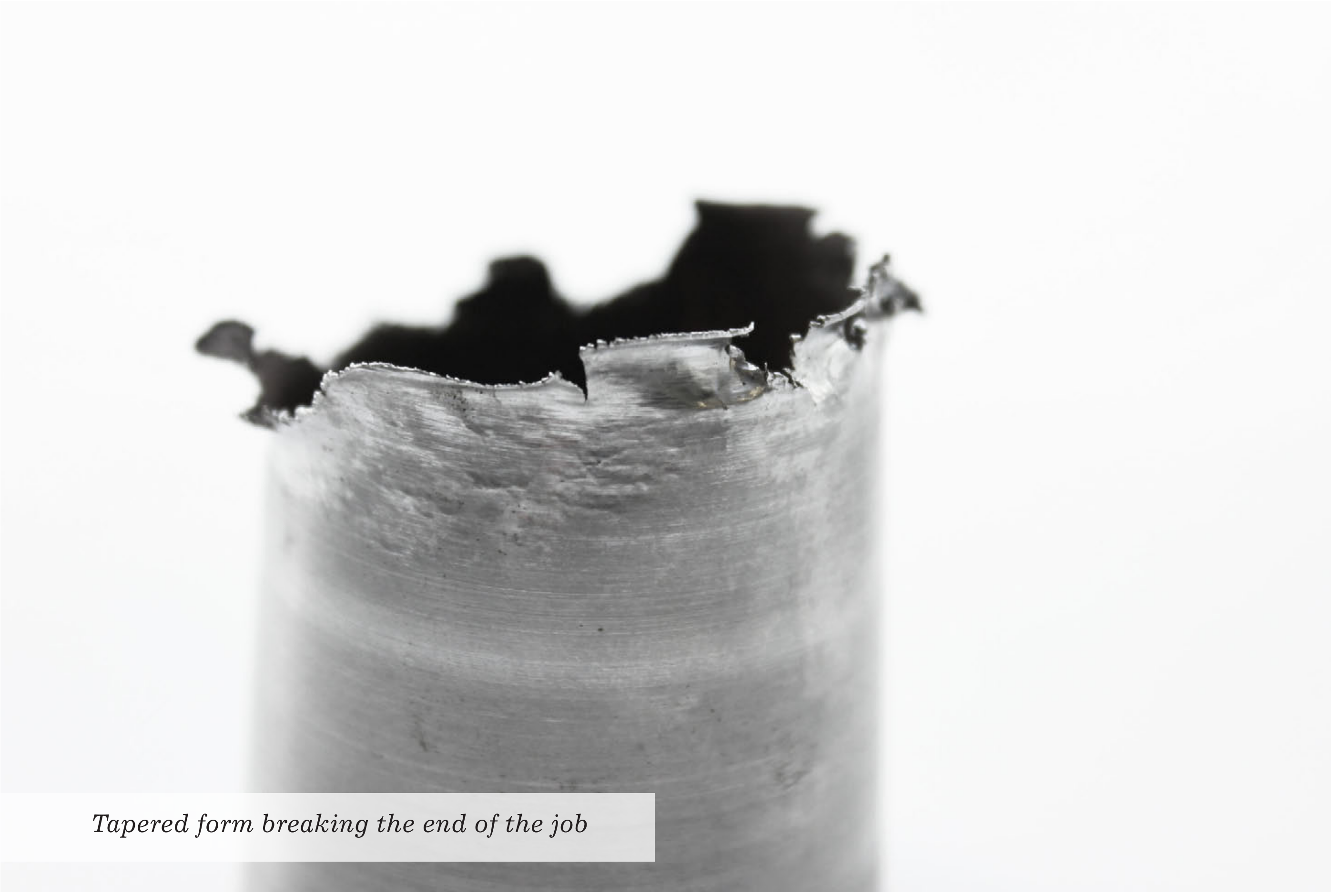
+ The thermal dynamics of metallurgy show us what temperature the swarf is as it produces different colours. A straw colour related to areas of the profile is generated at about 200 degrees centigrade transitioning to a purple colour and then blue generating 300 degrees, anything above that starts to dull the colour eventually to black.

+ Cutting off more material at a time at the fastest speed proved the machine was capable of cutting the material and thus embedding the object to gain a gradient of colours and the swarf rubbing the surface quickly melted onto the surface that gave an unusual tactile feel.

The tool after completing a job

Scrap Mild Steel Variable thickness

Varying thickness, material breaking



Tapered form breaking the end of the job

Salvaged Copper Tube

Parting Tool grooving marking

Spiral Starts

Watch face in mild steel, worn tooling

Tactile response from rough texture

Turning a profile down 6mm in one cut

Portrait of a rough surface

Shaving off 10mm in one cut

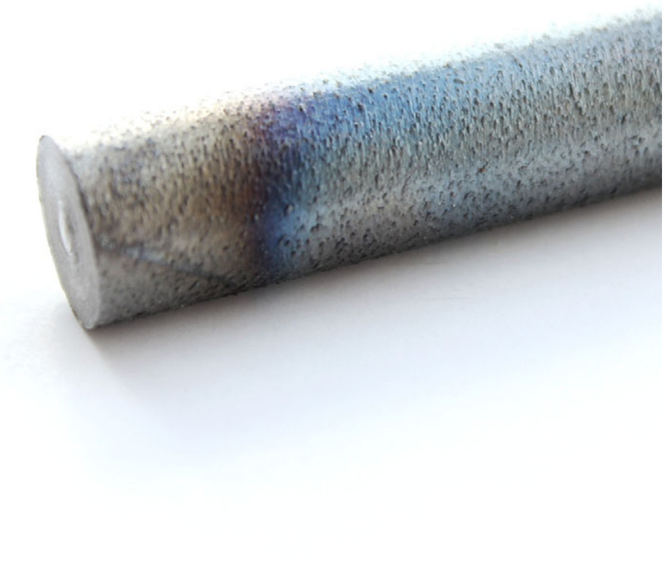
Shaving off 10mm, 5mm, 8mm (from bottom to top)

Turning from stock size to profile

Handheld prototypes

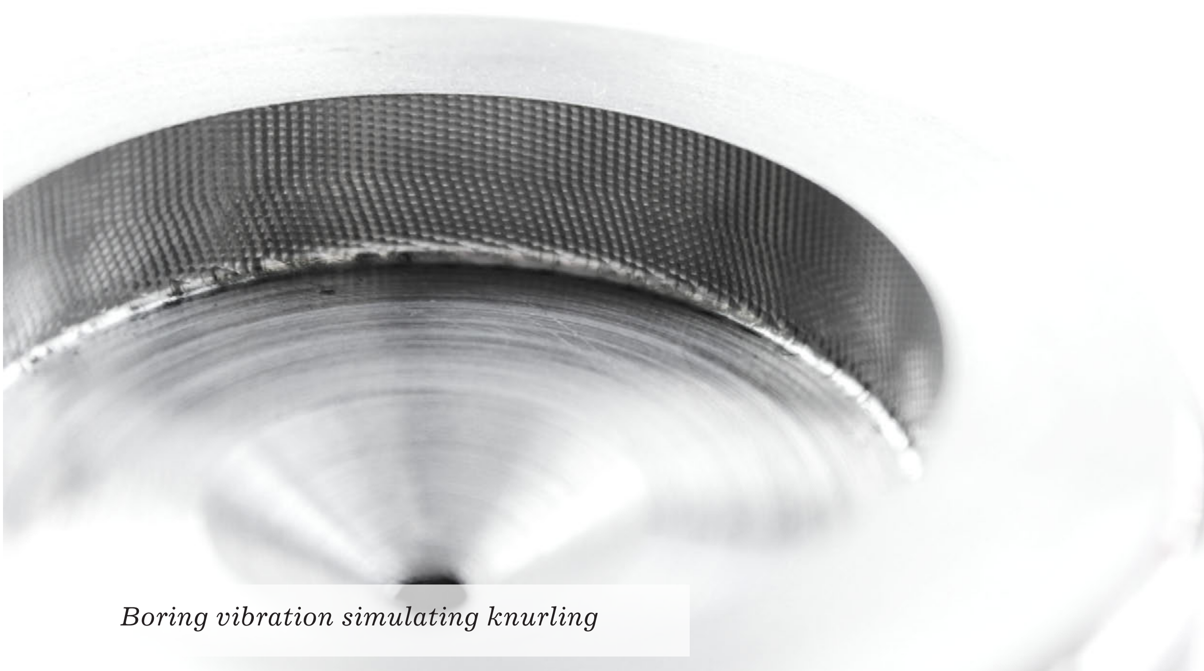
Turning to show heat change

Straw, Light Blue and Dull Blue



'Metallurgy' Range of Temperatures

Holding its colour and coarse grade



Boring vibration simulating knurling

SEVENTH SERIES

- Thin samples were created with small diameters and a shortened length which the machine comfortably turned, providing a need for a standard shaped to act as control in testing challenging the capabilites of what the machine could do.

- More spline deviations were tested on a profile that went to a point at the end to simulate the end of a pen and how that feature would change the way it was held.

- A test of tolerance was created to see how precise the machine is. It introduced a level of serendipity with the pneumatic pressure generated.

- The serendipitous nature of this experiment came from the tools not being used this precisely before and the need to callibrate them to the point where the gap of the aluminium sliding together was accurate to a thousandth of an inch. This required a lot of offsetting and false data in the g-code so that each experiment would get closer, the few experiment all proved to work with the pneumatic pressure requiring different amounts of load suitable to push the two parts together.

- Another invesigation into the spirals turning the material down to a smaller diameter and then expressing the spirals onto them.

- During this experimentation I decided to change the length of parting the job and ran the exact same code that had been previously passed through the machine which showed a different spiral.

- Analysing this change indicates that along with the (f) value and (s) value, the length of the profile being cut alters the outcome.

- Vibrations were further tested sticking 200mm or more out of the chuck to express strong visual tectonics of how aluminium resonated.

- Learning how to thread, creating the external thread on the CNC lathe and the internal thread on a manual lathe, practicing using metric, imperial and whit worth standards with drills, taps and dies.

Initial Thin tests from 1mm to 0.1mm

Aluminium vibrating 200mm out of the chuck

Testing tolerance to a thousandth of an inch

Different tolerances

Spiral effect on Mild + Stainless Steel + Aluminium

Different lengths changing spiral effect

Pen tips deviating to a point

The more gentle feeling of a thicker ribbon

Crackling from Mild Steel

Shallow spirls, subtle texture

EIGHTH SERIES

+ Approaching the final stages of testing different methods of manipulation there was still need to try new experiments and revisit old ones trying to find the control:

+ Performing more grooving operations onto mild steel revealed that turning the profile with tool 3 brings about a clean glossy finish and then grooving with the parting tool left a rough matte texture.

+ The rough thermal tests proved to have the most stirring results in terms of seeing the power of the machine, the heat generated and the loss of control with surface treatment.

+ To continue this discovery the process of creating a profile through small cuts was abandoned instead using a wider stock size and turning it straight into a tear drop or diamond shaped form with a single cut using tool 1.

+ Shaving off 6mm, 8mm and 10mm at a time at speeds upwards of 1200rpm with no coolant produced some sparks and smoke, and when the job was parted off it was sizzling in the swarf.

+ The varied amounts being taken off left some visually fascinating markings and under inspection could be repeated again.

+ With this procedure of turning a large amount of material there was a truly unforeseen moment as the chuck pressure, measuring in psi, was set to 290 capable of holding all the previous experiments comfortably. On this particular operation the amount of force tool 1 provided ,cutting 10mm of material off at once, caused the material to move back in the chuck. Hinting that the tool went forward pushing the rod back and then cutting back into the material as it moved along the declining line producing stepping in the model.

+ All the rough profiles showed signs of thermal dynamics again but there is difficulty in getting the entire rod the same temperature to produce the differing colours across the length.

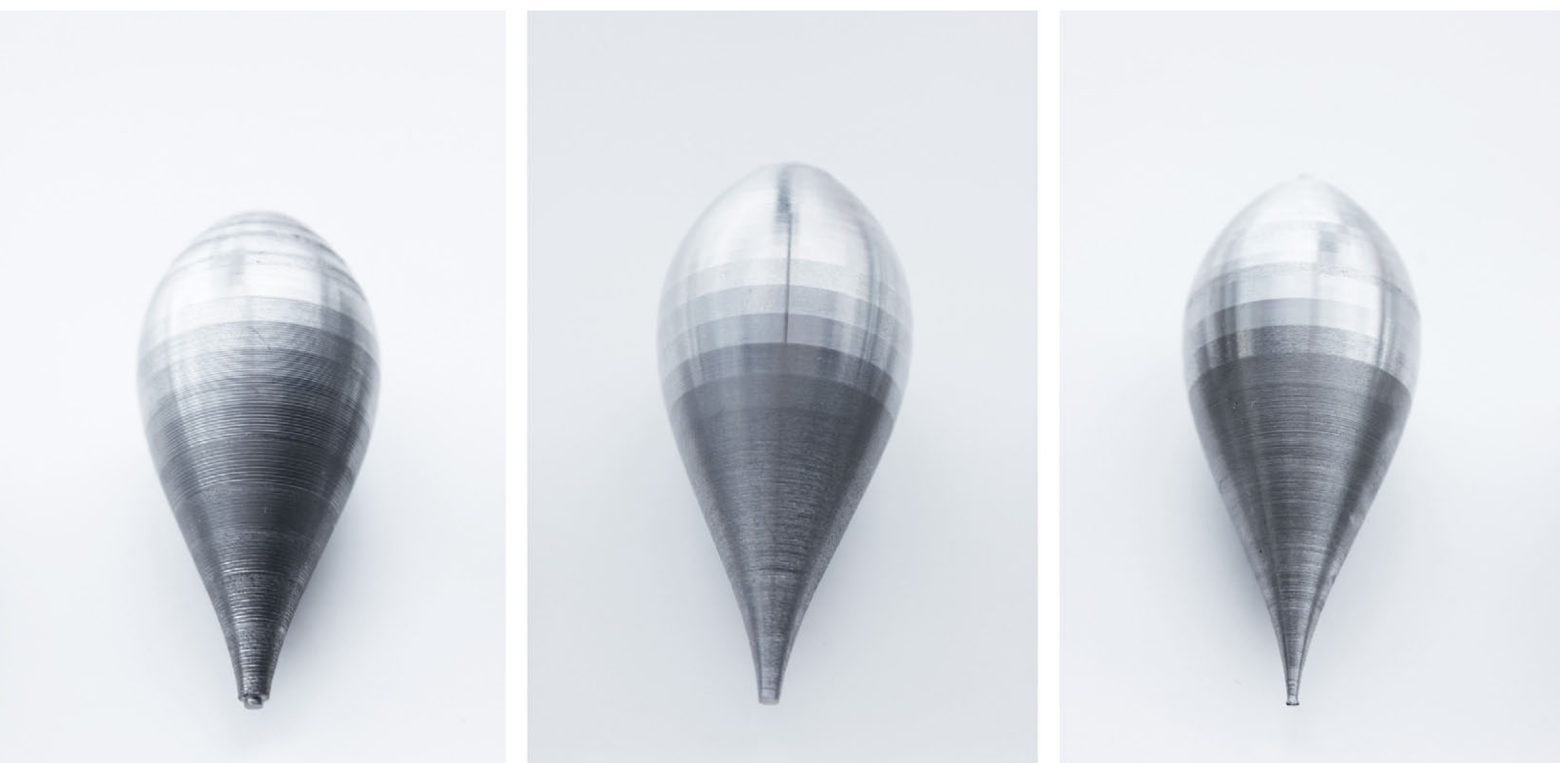
Grooving with parting tool, rough finish

Pendant form rough profiles

Tear drop rough profiles

Swarf gradient from straw to dull blue

(From left to right) one cut profile at 1200rpm, rough cut at 1600rpm low chuck pressure, 2000rpm increased chuck pressure



(From left to right) 1800rpm, 1600rpm and 1400rpm, differing tones over the profile

The rough profiling did not break any tools but it did achieve a lot of wear and tear on the tool ends. This provided a new attribute to investigate:

+ Curved forms were used to test where the most wear had occurred, this could change depending on what was being machined previously.

+ On the profiles contours the worn tool manufactured a matte effect on the incline and a gloss on the decline, splitting at the apex quite precisely.

  This is based on the front of the tool doing the majority of the work and the back of the tool being left mostly unscathed.

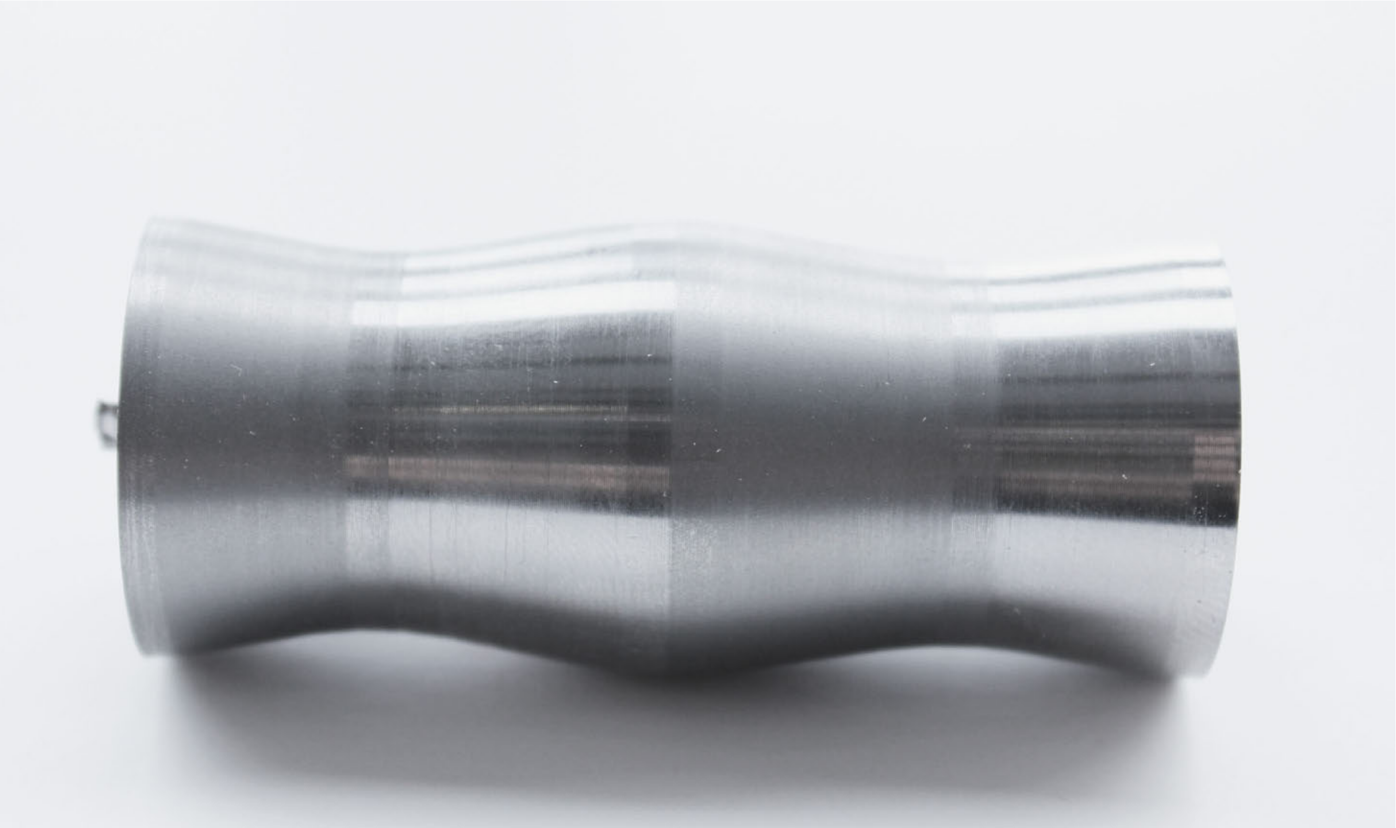
+ A completely broken tool would provide a cracking effect on the profiles as it would be cutting the material with a completely rough edge. The spirals demontrated the slightly broken tip showing the cracks in the grooves.

+ Introducing acrylic provided a study into how well it turns as well as the optic qualities that could be shaped whether it be a clean finish fragmenting light through the type of profile or a filtered light through a matte finish.

+ The next qualities to be thoroughly tested were the thin samples, one set for acoustics and another starting at 1mm working down to 0.1mm at regular intervals.

+ The machine easily manufactured each sample and only at 0.1mm did it flex the material, without tearing it, meaning the form was irregular and the wall thickness varied.

+ Achieving this minute wall thickness prompted an attempt at metal spinning trying a few different methods of spinning outwards, inwards and over an attached mould. There was success for a brief period of time, being able to form the metal briefly before it ripped apart under pressure.



Matte effect on tooling incline and Gloss on tool decline

Matte and Gloss repeat, more curvelinear form adding vibration

One cut from curved form, melting swarf onto the model

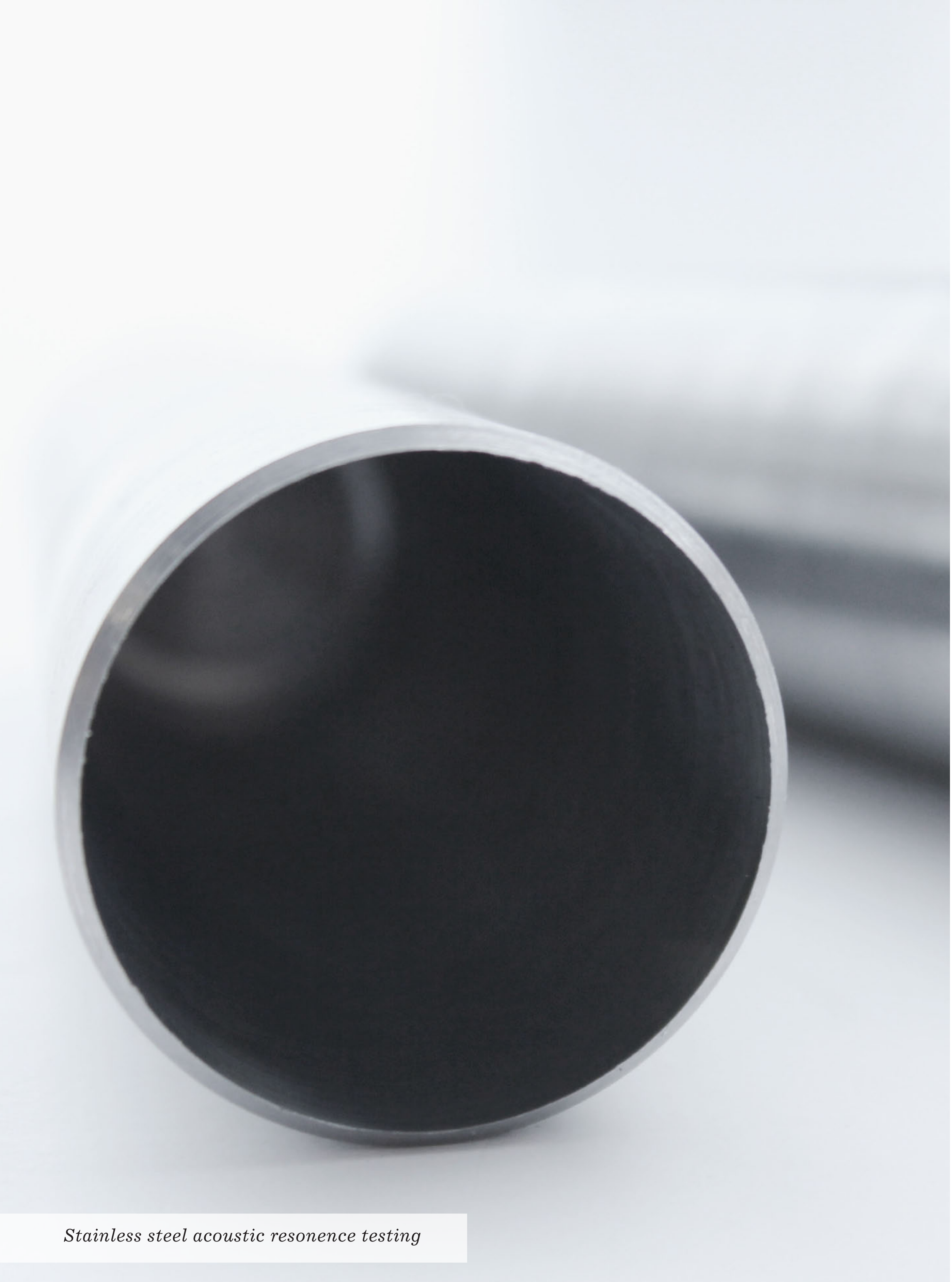
Rough marks from extreme heating

Thin tests from 1mm to 0.1mm

0.1mm showing oscillation

Watching were the spline deviations form

Acrylic optic qualites



Stainless steel acoustic resonence testing

Consistent blue swarf

8

final composition

S-Series

8
FINAL COMPOSITION

The final composition for this thesis needed to showcase the experiments with most potential, expressing the tactile, aesthetic and valued qualities. The final presentation provided discussion on how to consider the design elements, engaging character into the products. The pen would be a fantastic way to compile the findings and cycle back to a previous project in the undergraduate degree (INDN 211), which used the CNC lathe to make either a pen or a vessel.

Much like the chess set there is a deep tradition in making pens, related to lathes where the craftsmen have made so many iterations, all so unique, before the final iteration going onto series production. Three traditional and famous mass manufactured pens were chosen; The Montblanc Meisterstuck 149, the Pentel R50 fibre-tip and the Omas Tokyo by Ettore Sottsass, these have all gained cult status since their creation respectively in the 1950s, 1970s and 1990s. The Meisterstuck 149named for a final year project for young craftsmen, marking the transition from the apprentice to master, representing luxury, tradition, culture and power. Made with celluloid originally but replaced with resin and individually made to be tailored with various points and flexibility in the nib. The R50 has been described as the Model T ford of writing instruments, it has the same iconic virtues in mass production, value for money and made in one instantly recognisable colour. The Omas Tokyo is different from Ettore Sottsass' previous work made on clean and simple modern lines seeing the construction of a stunning pen.

The form of the pens were used as a homage to the design and designer, as a way of showing added value through surface qualities. Demonstrating the changed appeal through materials and one off objects subject to customisation, through the designer, in a series.

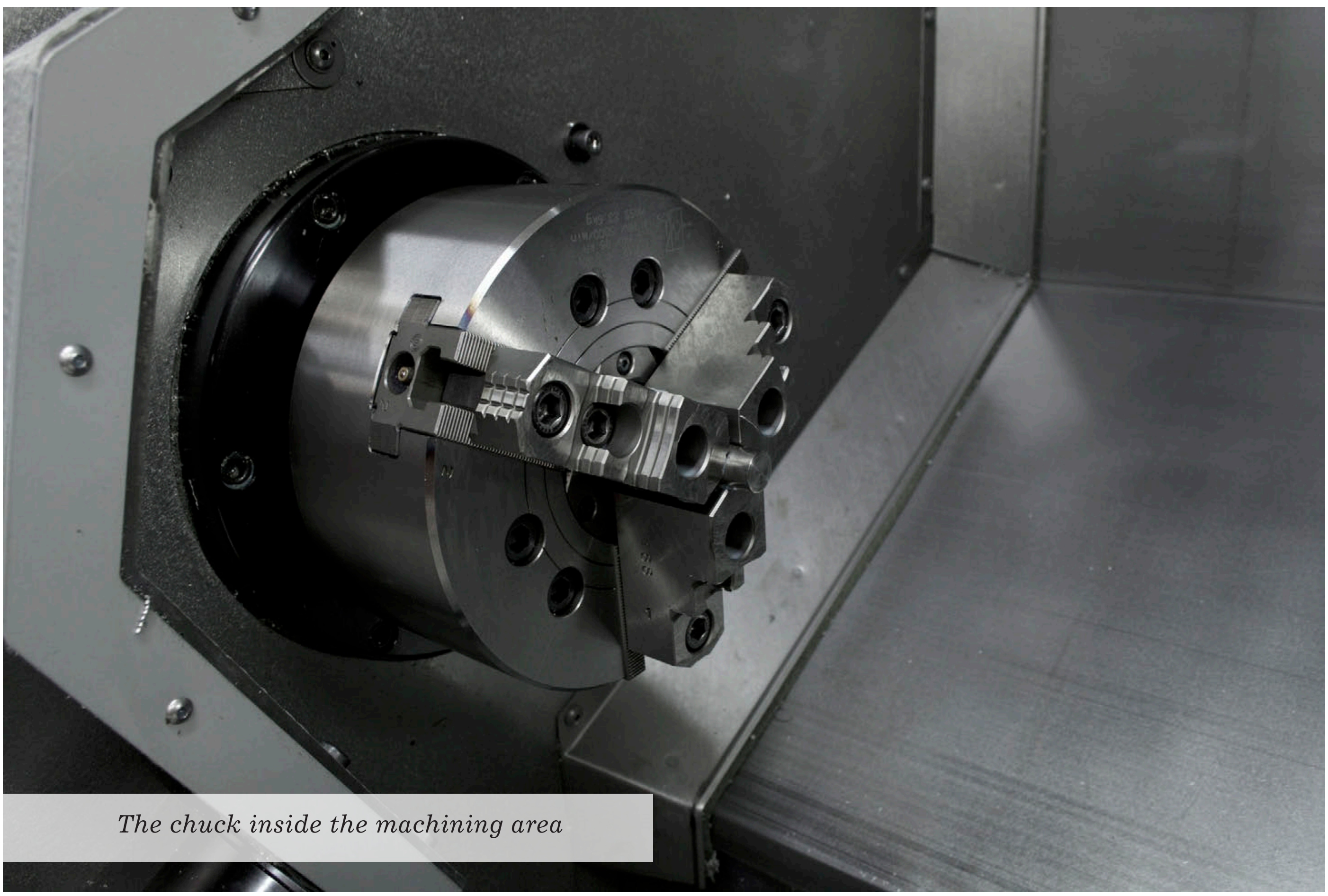
CHOSEN DETAILS

+ *Spirals*
+ *Rough profiling*
+ *Faceting*
+ *Tool wearing*
+ *Tolerances*
+ *Thinning*
+ *Thermal dynamics*
+ *Vibrations*
+ *Chuck pressure*
+ *Materiality*

Developing an understanding of the machine

Haas details


Chuck pressure guage


The chuck inside the machining area

Montblanc Meisterstuck 149 (1924)

Pentel R50 (1960s)

Omas Tokyo by Ettore Sottsass (1990s)

Aluminium 250mm from the chuck

Lid tolerance over a rough surface

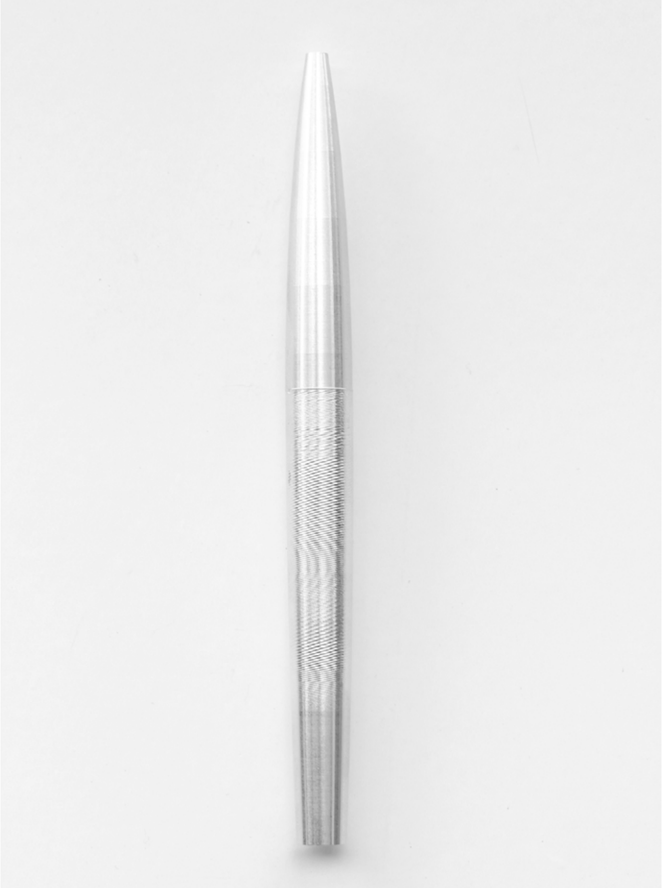
The chamfer from the back of the tool stepping down

Half size Pentel R50 replica

Tool wear and vibration

Thin Pentel form in aluminium

Moire pattern on stainless steel

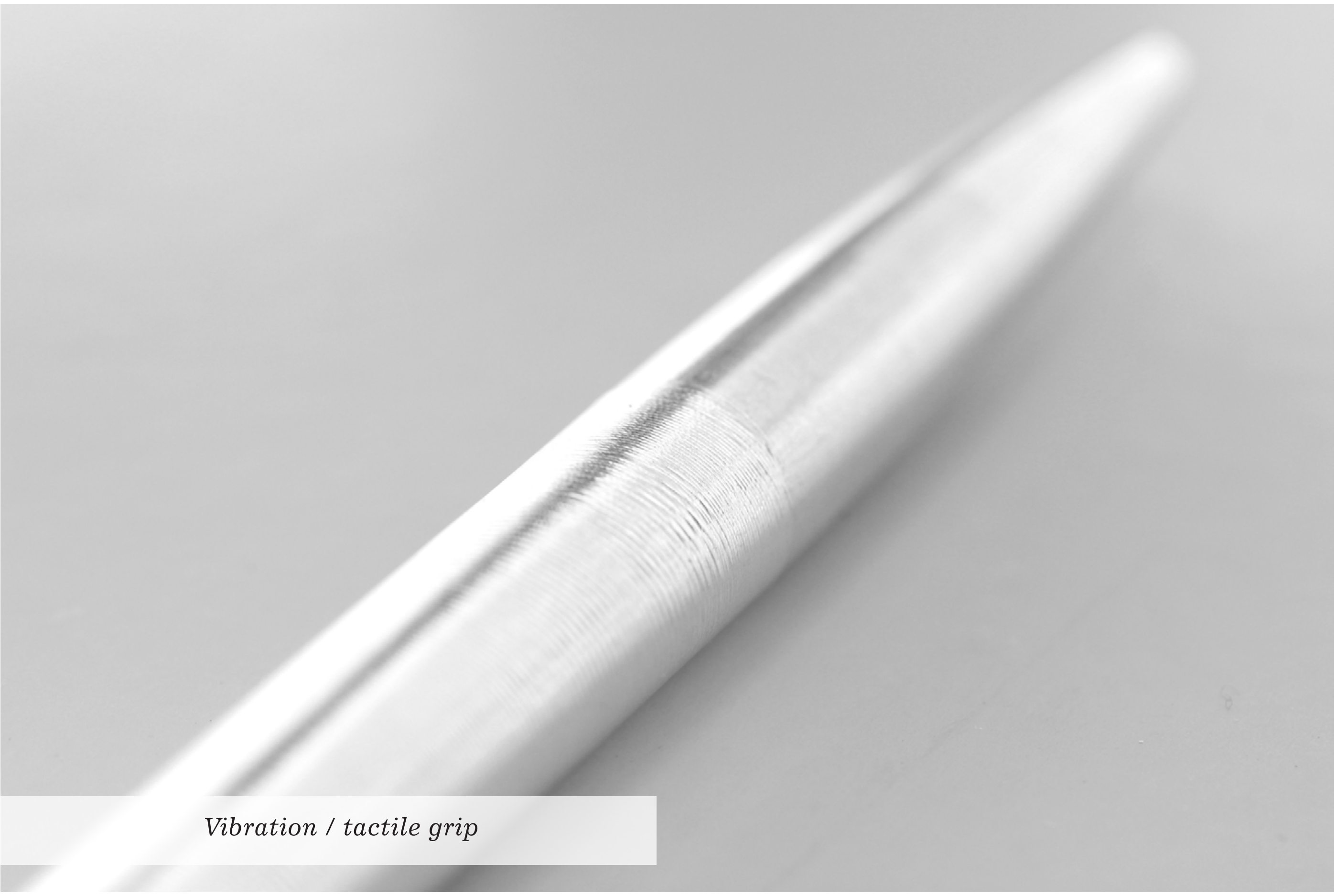


First Montblanc sample

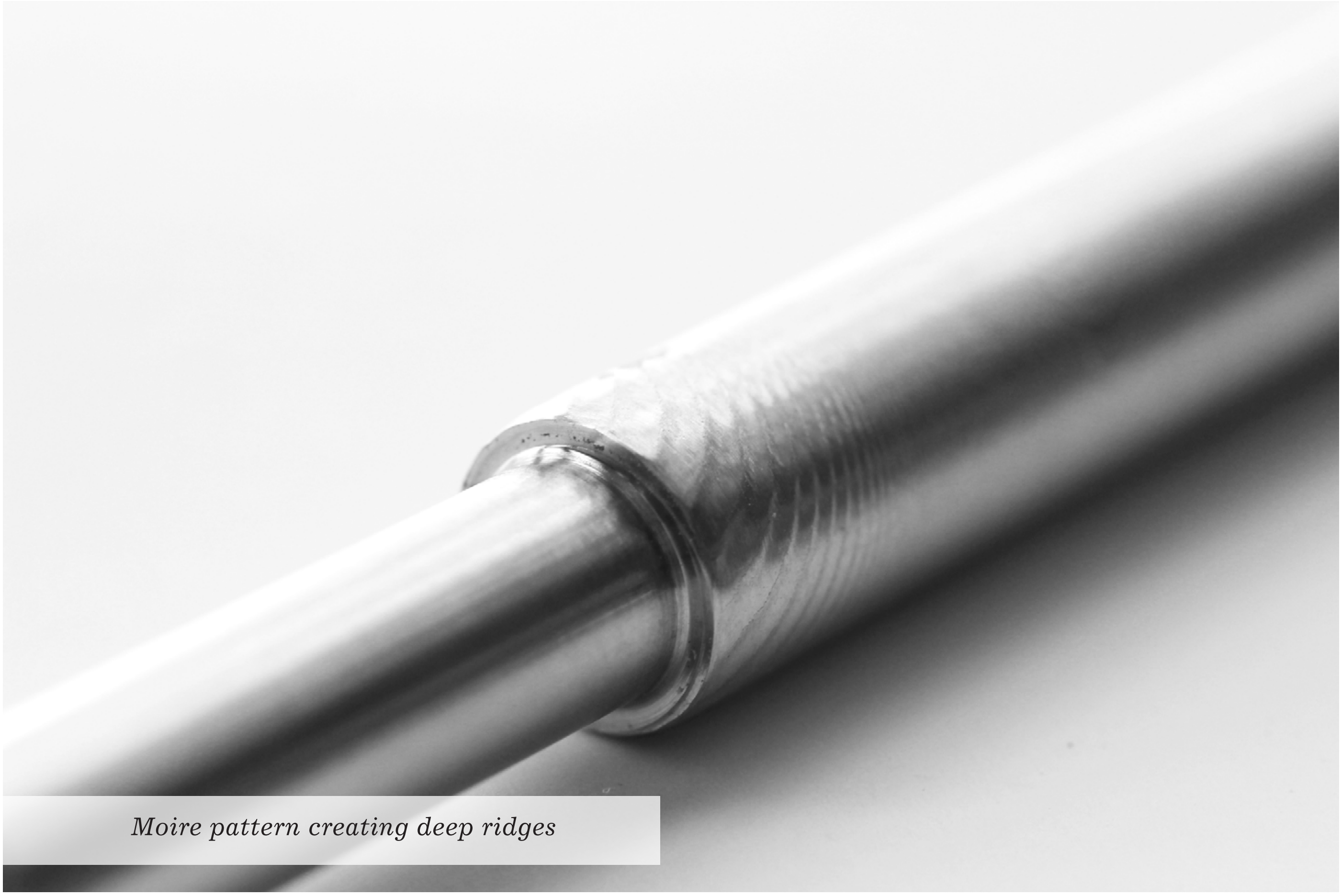
Omas Tokyo in Mild Steel

Stainless steel / Moire pattern with breaks

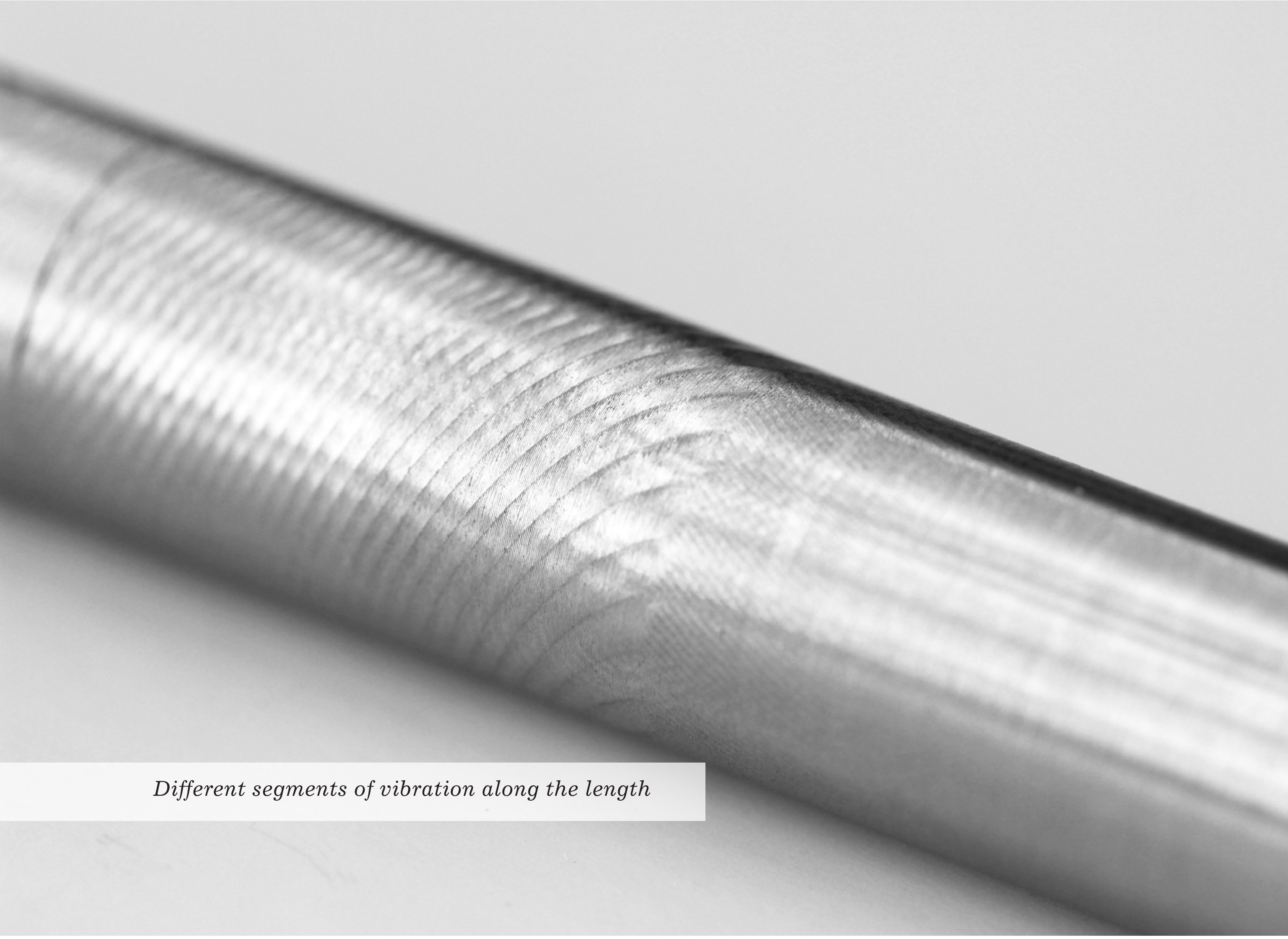
One pass to profile (straw colour)



Vibration / tactile grip



Moire pattern creating deep ridges



Different segments of vibration along the length

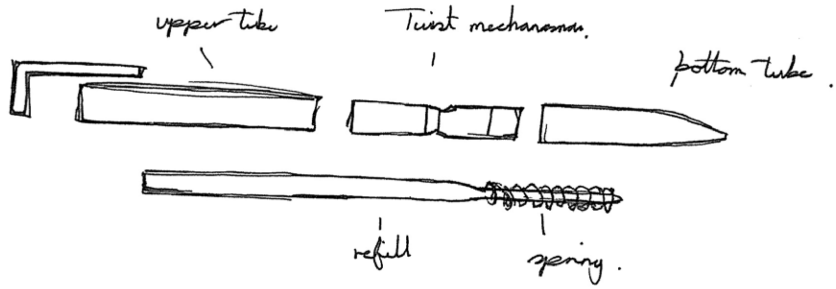
Judgements on the materials to use were mild steel, stainless steel and Aluminium to give the pens an immediate high quality in production and aesthetics. The greyscale tone also put the attention solely on the surface texture being created; the material opposes what the original pens were manufactured with. Another selection was the particular type of pen as you had a fibre tip on the Pentel, a fountain pen with the Montblanc and Omas and then there was ballpoint pens. The choice was to head towards the modern fibre tip creating a contemporary drafting pen using a Pilot Hi-Tec-C Ink cartridge. This ink cartridge made the configuration of the pen simpler and more efficient to calculate dimensions, threads and closure.
Machining the qualities on all three archetypes at full scale came up with more interesting results, the Moire pattern more prominent on the longer length of the pens and becoming more tactile when held in the hand. The pattern was also accentuated by having 900mm of material sticking out behind the chuck created great vibration throughout the whole machine. Some of the forms' geometries created abnormalities in the code with the spiral information on one job making the tool immediately cut back through the metal when retracting thus creating a reverse spiral. Stepping down towards the chuck on the Pentel replica resulted in chamfers being naturally caused by the backside of the cutting tool, discovering another feature to account for.

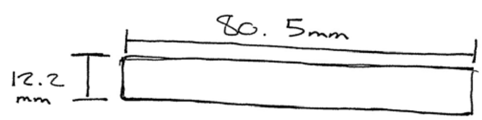
HI-TEC-C 0.4mm ink refill

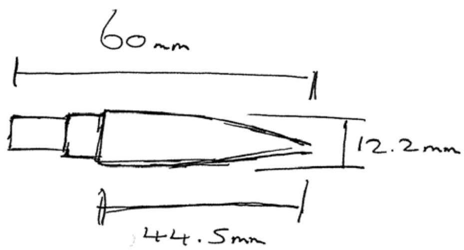
+ Twist mechanism.

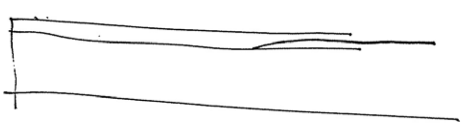
+ Pen Press.

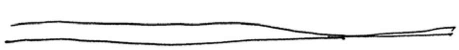
+Mechanical Pen
Pull apart.

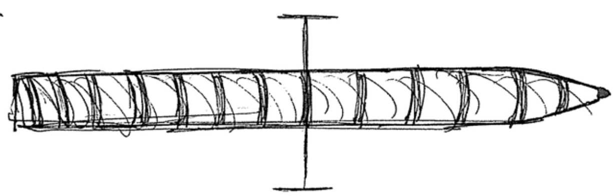


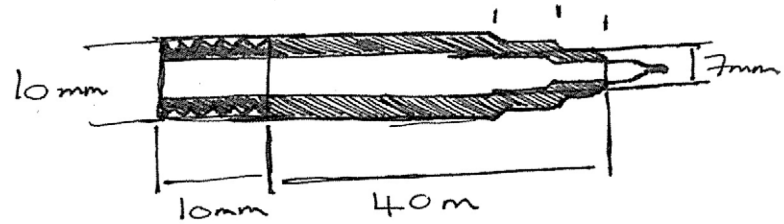


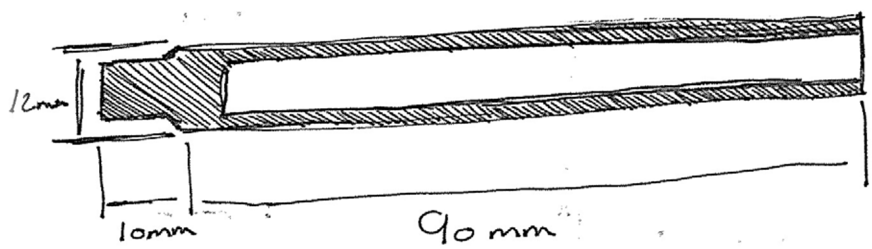


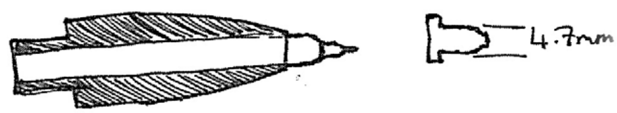


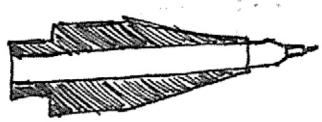


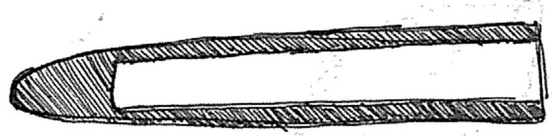


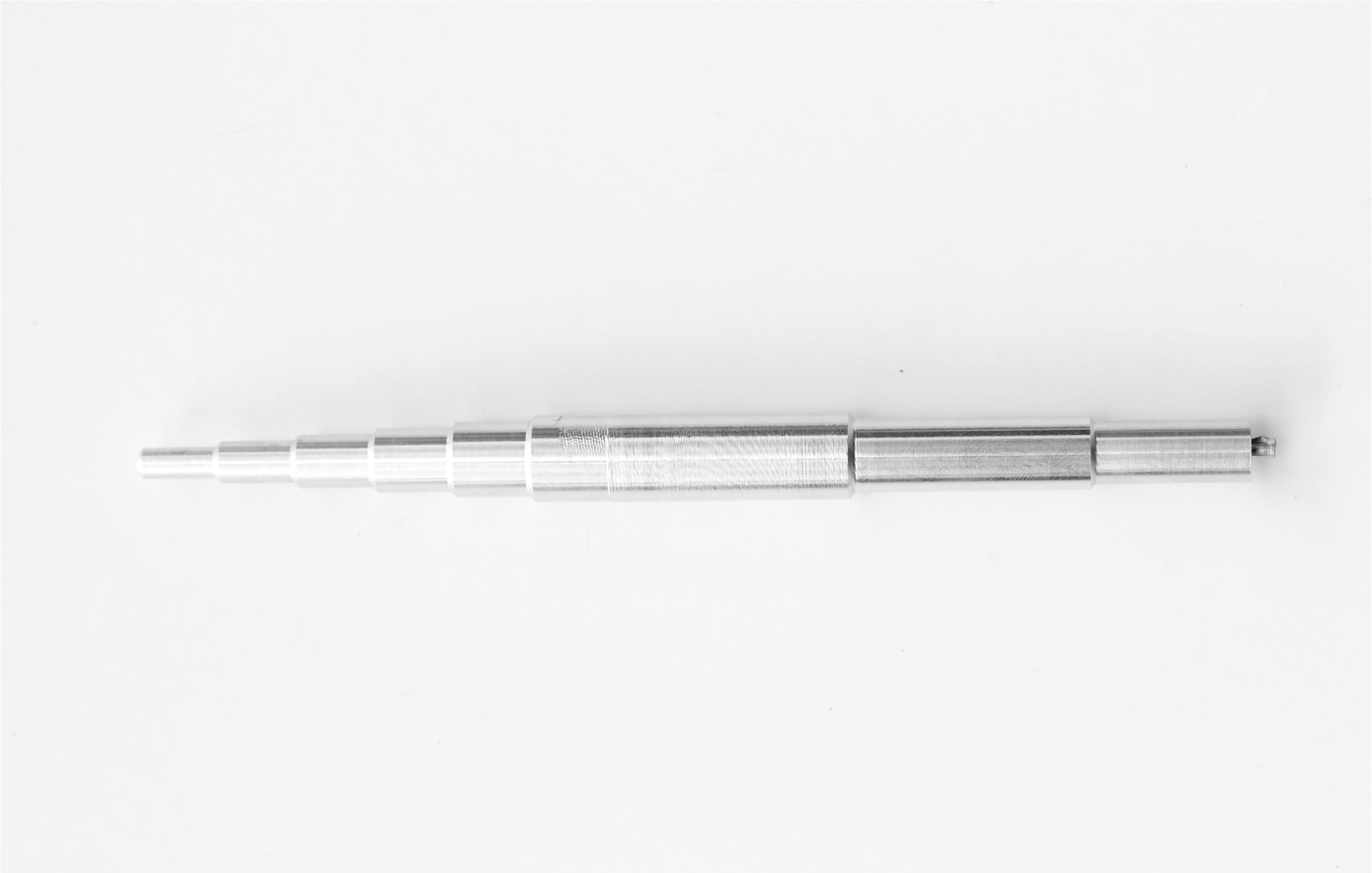

10 mm
7mm
10mm
40m


12mm
10mm
90 mm


4.7mm







Stepping the Montblanc profile

Accurate measurements for the Montblanc

Stainless steel tip and aluminium body

Rough mild steel and aluminium spirals

Vibration on aluminium tip and mild steel base

Rough tactile tip for better grip

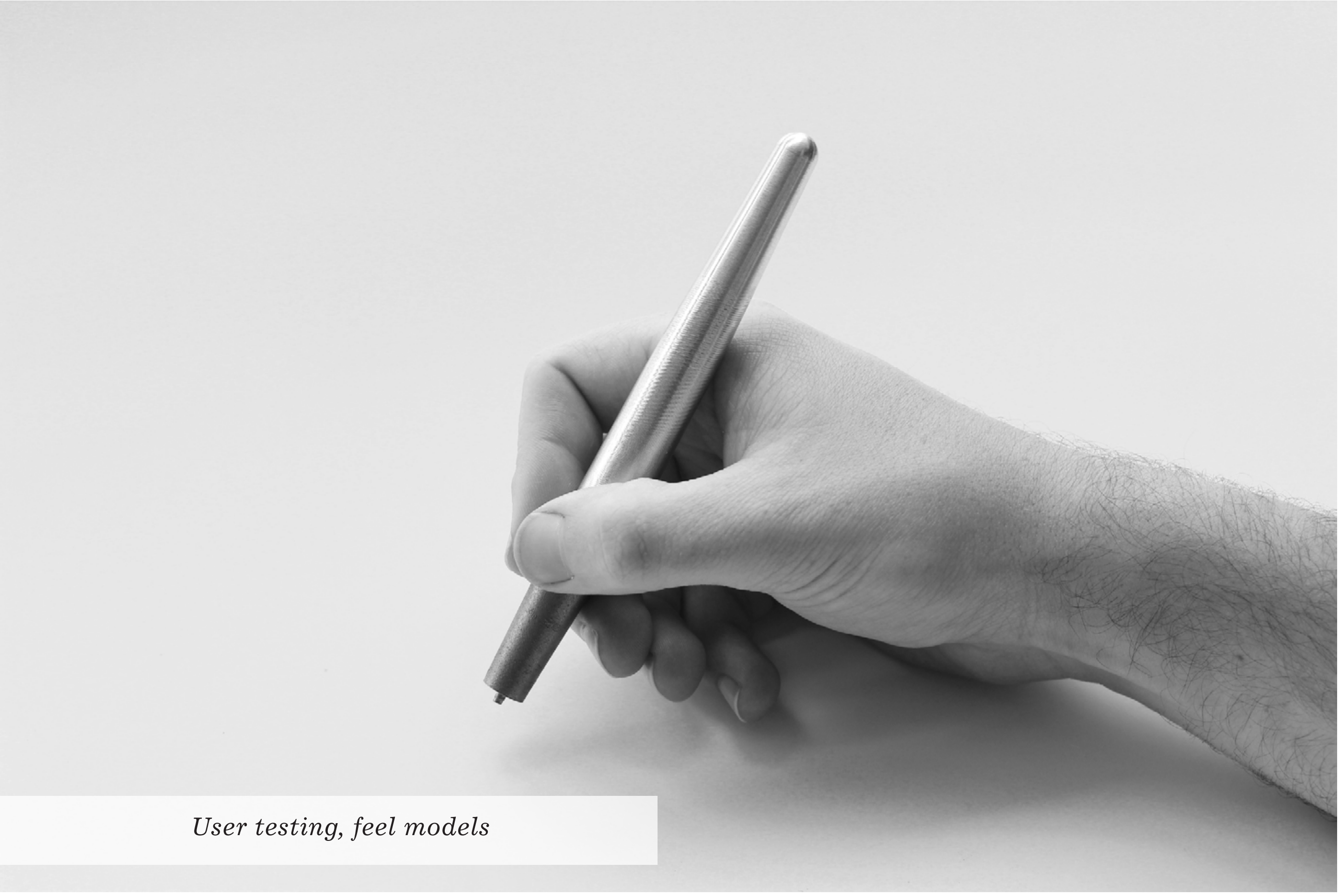
The contrast of colours with materials

Faceting definition

Tool wearing

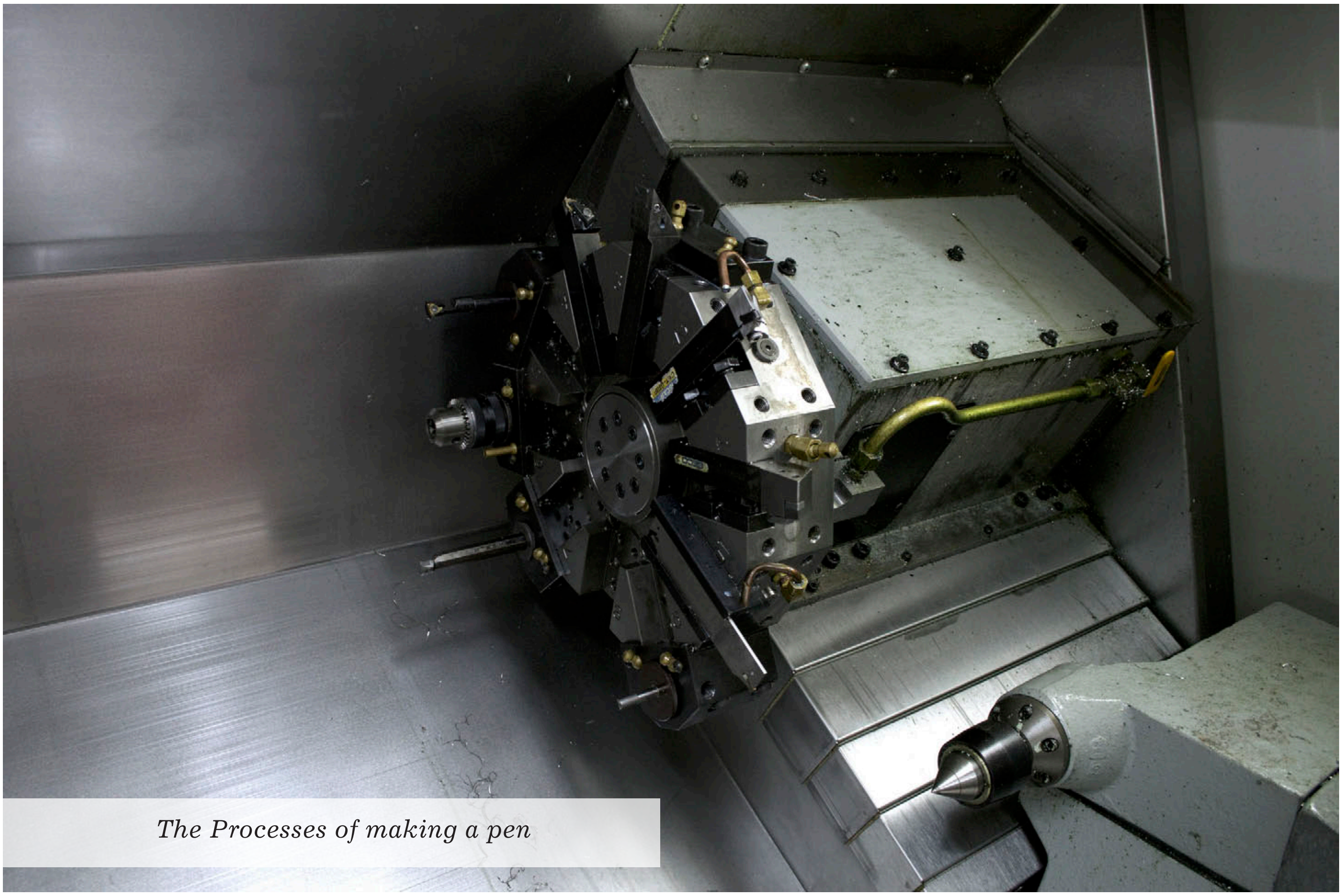
Subtle spirals

4mm spline deviation / sharp spirals

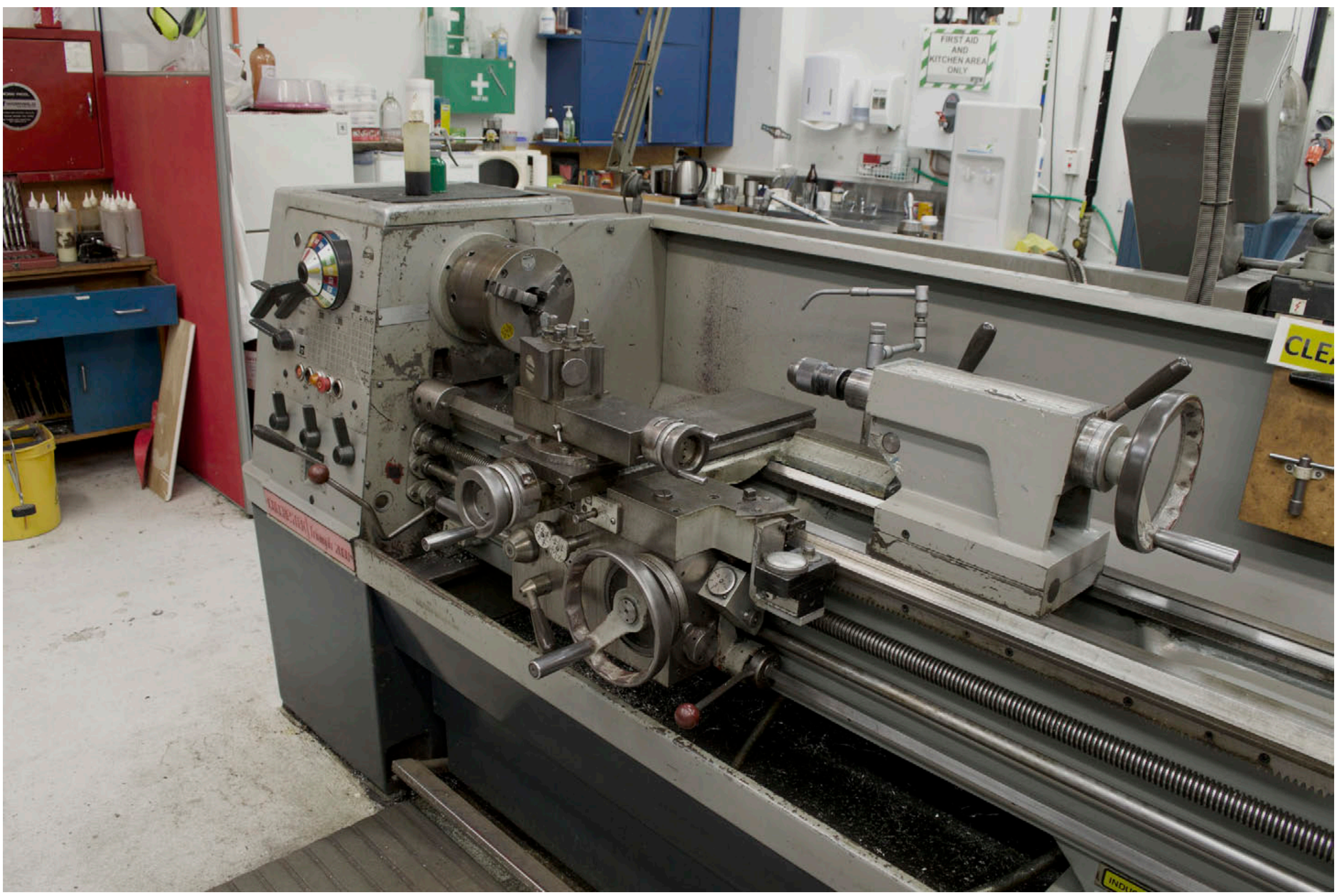


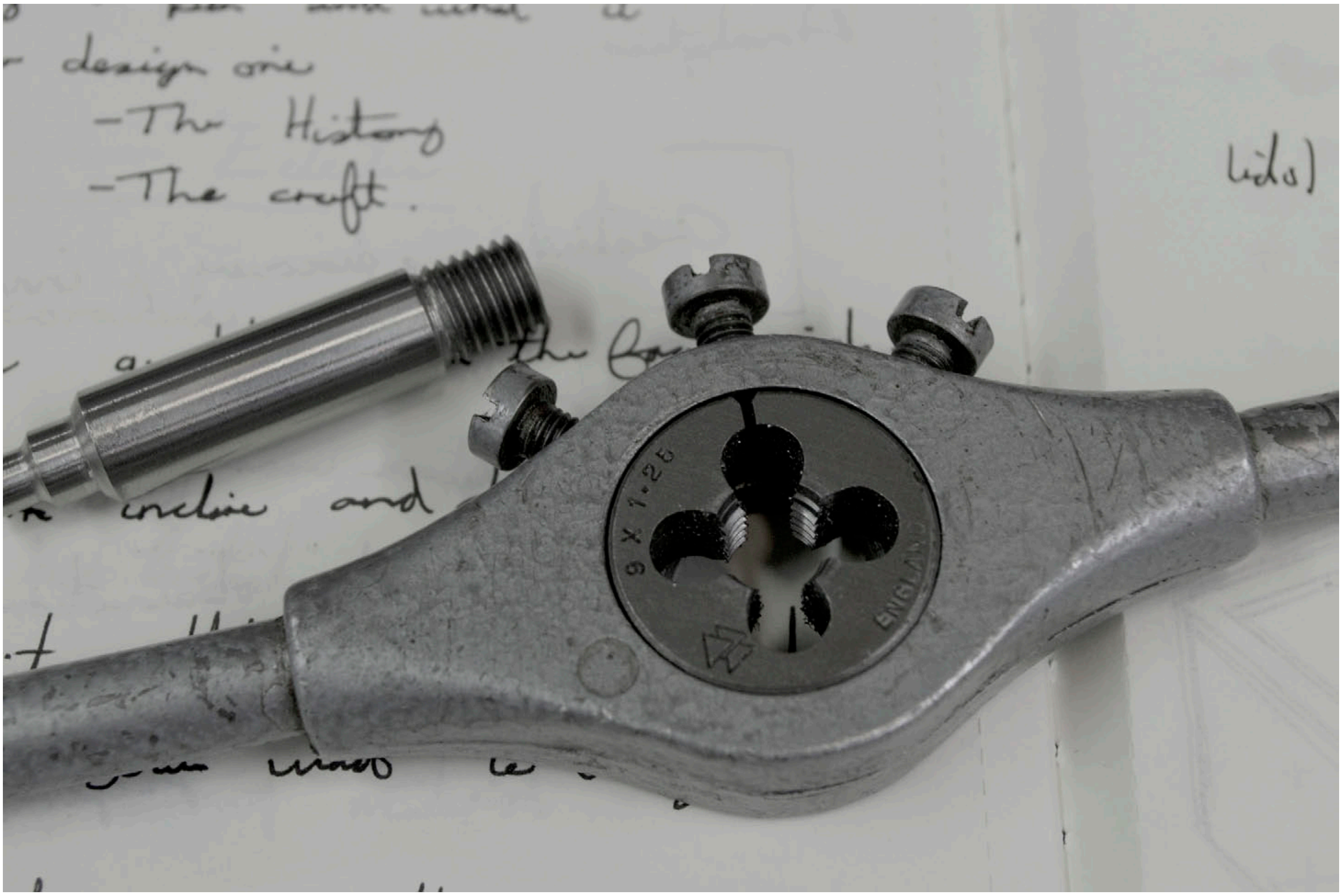
User testing, feel models

Beautiful result / cross patterning



The Processes of making a pen





Manual procedures

Learning techniques

CNC parts ready to be manually turned

Hollowing out of the pen shells

Machining the qualities on all three archetypes at full scale came up with more interesting results, the Moire pattern more prominent on the longer length of the pens and becoming more tactile when held in the hand. The pattern was also accentuated by having, at first, 900mm of material sticking out behind the chuck swinging created great vibration in the whole machine. Some the forms geometries created abnormalities in the code with the spiral information on one job making the tool immediately cut back through the metal when retracting thus creating a reverse spiral. Stepping down towards the chuck on the Pentel replica resulted in chamfers being naturally due to the shape of the tool on the back side of it, this was easy to capitalise on.

After working with the forms the choice was made to continue with the Montblanc and Pentel, as they were curvaceous and linear, the Omas sat in between the spectrum. More specified control on each feature and the function saw macro level changes in the surface texture, the pen tips getting to the correct specifications creating vibrations on the individual spline line, revealed when shot with a macro lens on a digital slr. The spirals had another change introducing a cleaner cut when doing the 3 pass cut, breaking the tool on the first pass making a Montblanc pen, and missing the next two passes. This left a single spiral throughout the profile that had a cleaner finish and a much more defined style. Consideration into which was to machine the pens was taken to generate a deeper vibration pattern and once the pens were assembled with the correct threads, weight was analysed to find the best material combinations to allow for comfort when using the device.

Return rapid cutting through the job

A close up of the reverse spiral

Differing values on the tip and base

Consideration to the assembly

Deviation 2.5mm

Linear finish on the end before finishing

Tool breaking on first spiral pass

1 pass base and lid

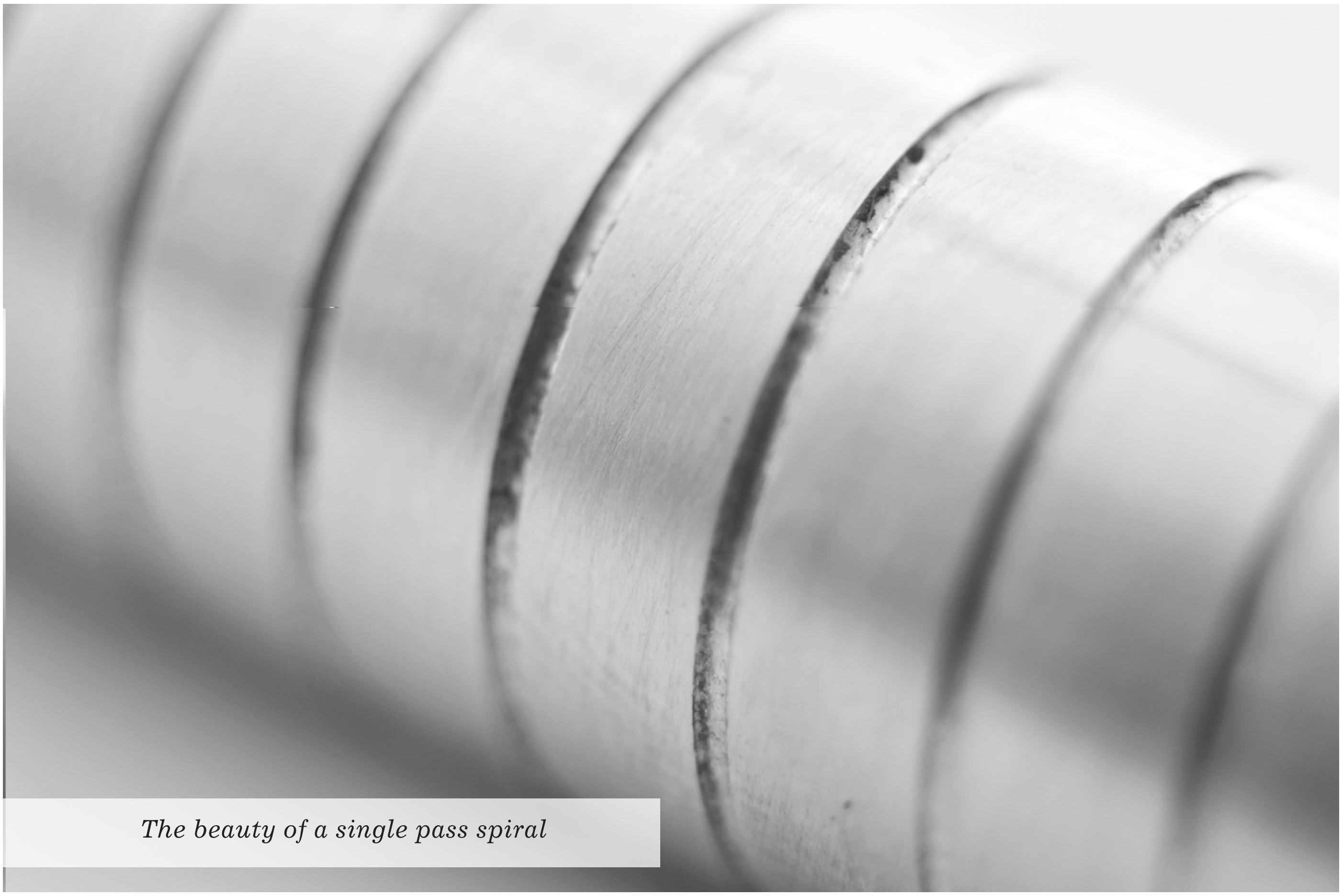
Low vibration stainless and defined spiral

Full two part pen assembly

Montblanc macro detail / spline deviation / fingerprint

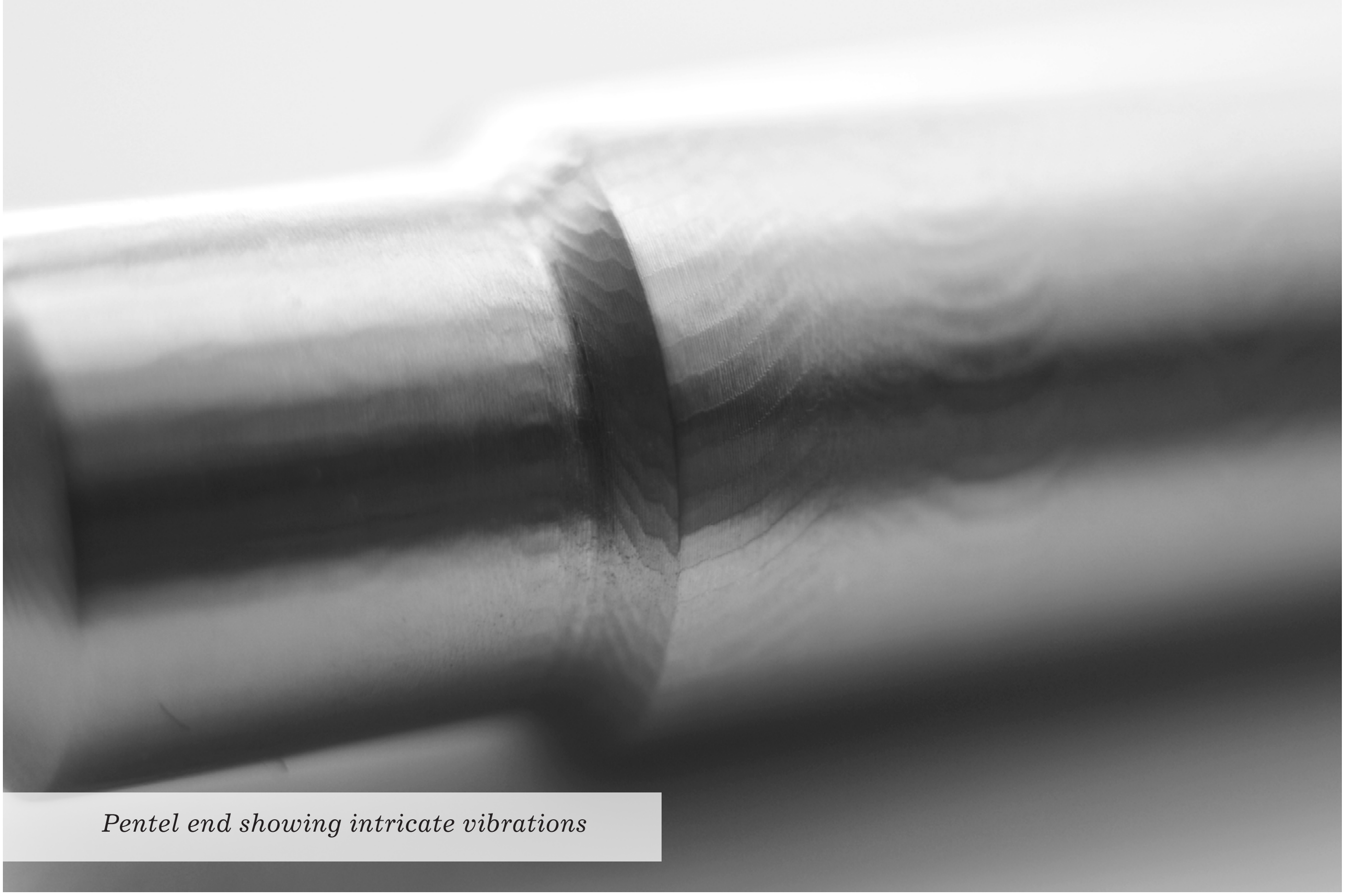
Patterning on the chamfer / changing with thickness

Scarring where the tool broke



The beauty of a single pass spiral

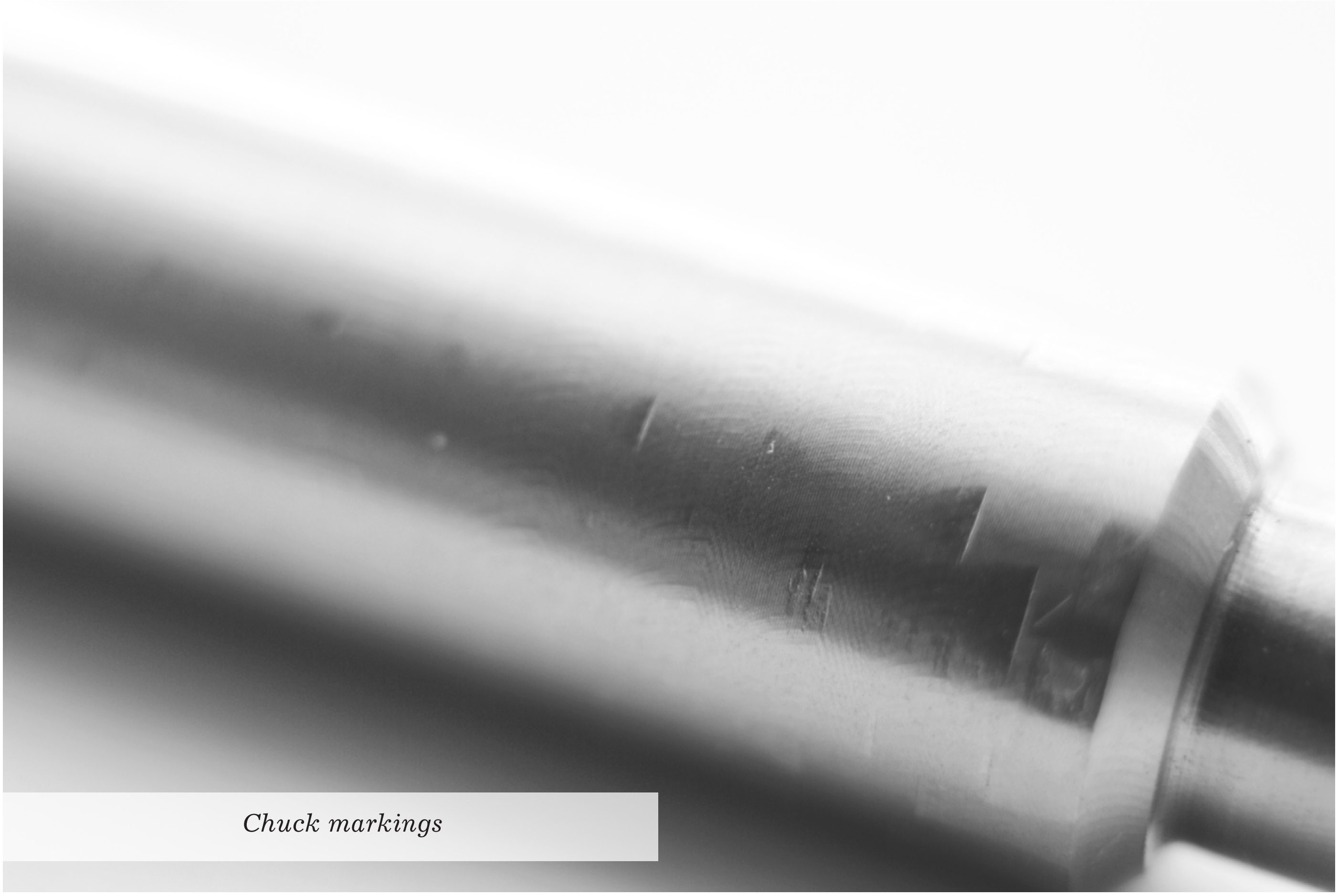
Three pass spiral / second and third pass creating rough texture



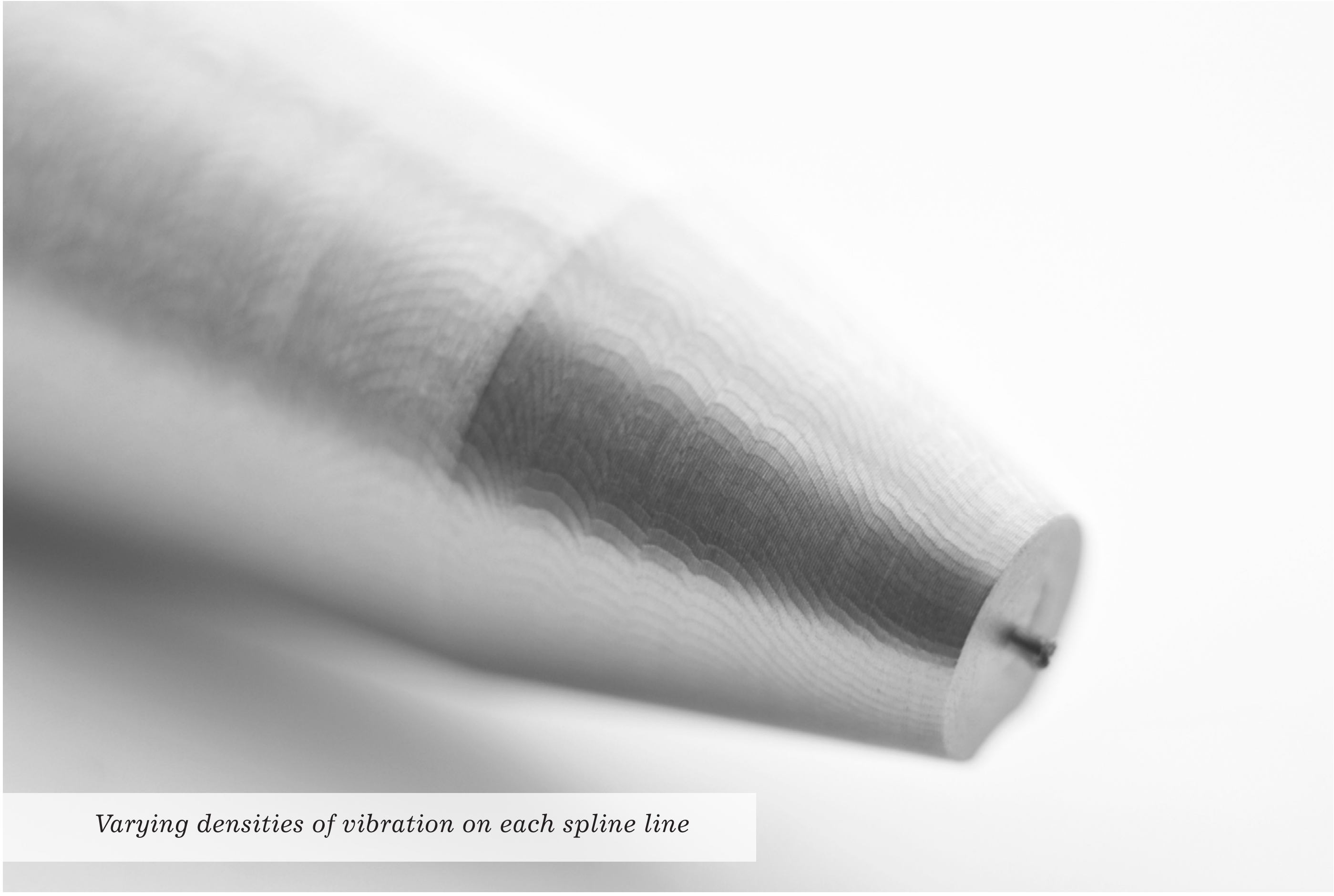
Pentel end showing intricate vibrations

Three consistently different sized bands

Clean tactile quality from a single cut

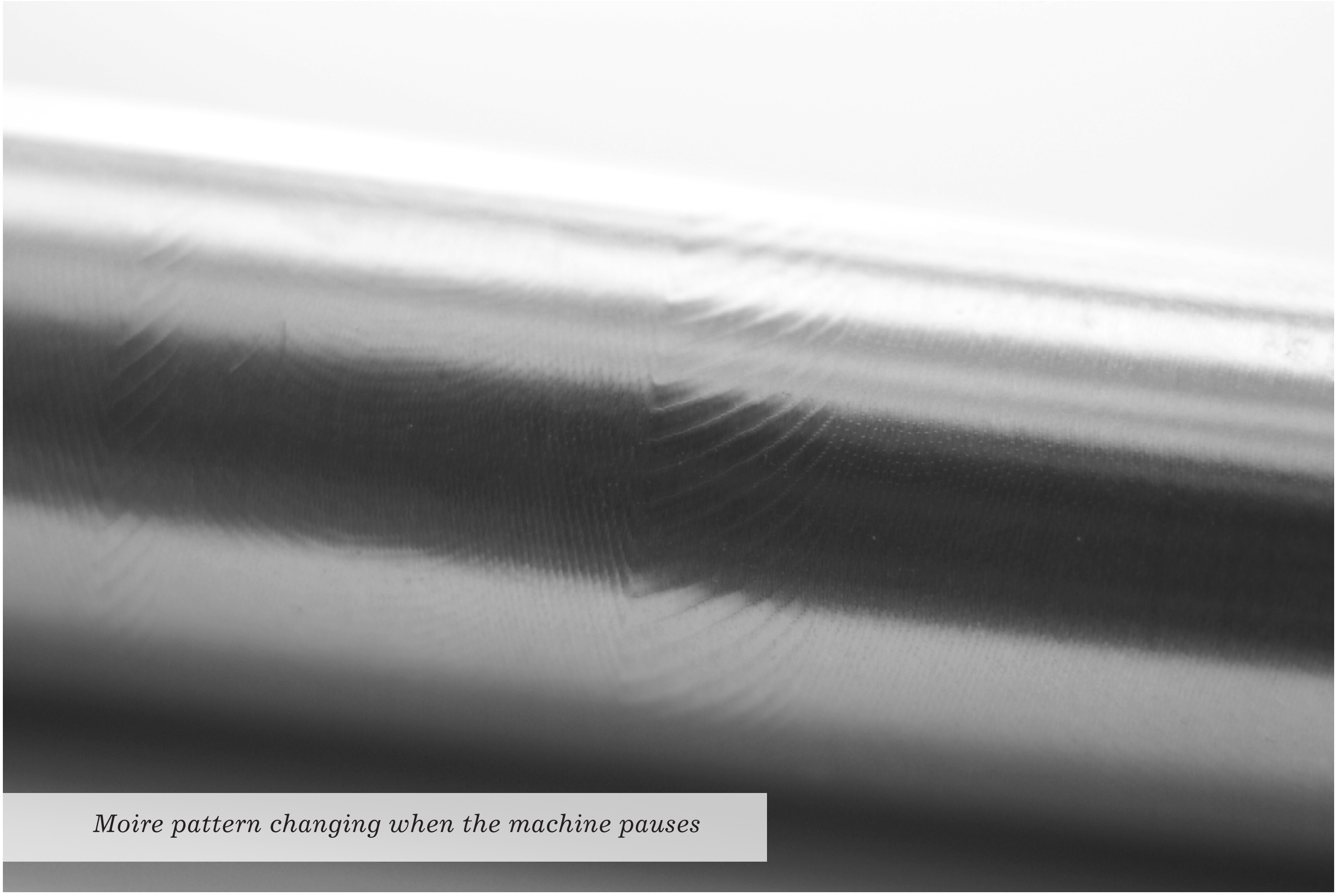


Chuck markings



Varying densities of vibration on each spline line

1.0mm spline deviation / patterned texture



Moire pattern changing when the machine pauses

Adapting and redesigning some features of the pens, lead the resolution of having the Pentel replica as the evolving final form of the thesis. It was a linear pen with some clean modern geometry that would give all attention to the digital tectonics displayed on it. The craftsman role appearing, by using the machine more so as a tool changing something in each step of the procedure.

+ Using the vibration and resonance in the materials.

+ The spiral texture both vigorous and subtle.

+ Exacting the tolerance of the lid to slide on and be playful with pneumatic pressure.

+ Spline deviation on the end of the pens for better grip.

+ The combination of materials allowing for enough weight to apply minimal pressure on the page with your hands.

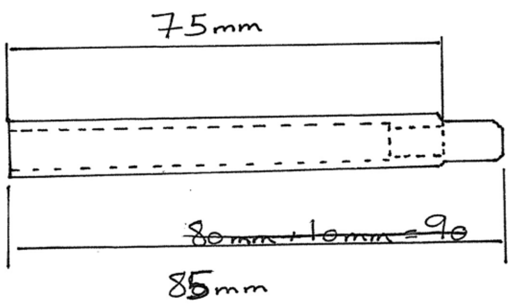
+ A polish to give it the clean complete high quality aesthetic.

There was a lot of attention to detail given, receiving criticism of finding the gap between too serendipitous and too engineered; creating a series of designs that fit the criteria. The technical and methodical approach to the final composition had engineering influences but the designerly creativity the entire way.

Tolerance Lid.

Complete pen size = 140mm

aluminium lid with Steel Body.



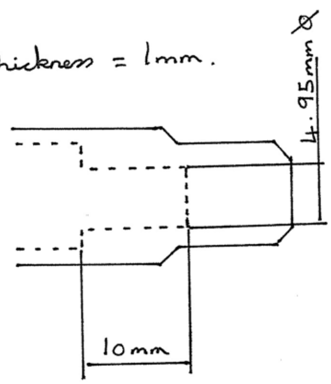
Pentel Spiral base = 12.45mm ø

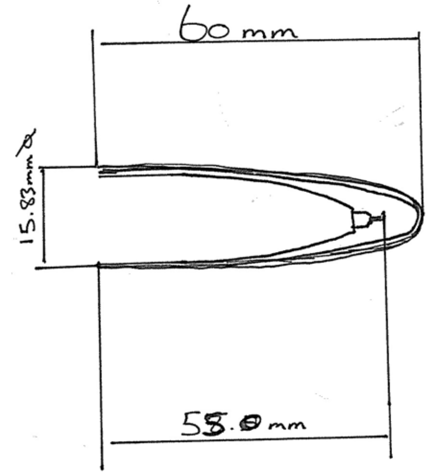
Pentel Vibration base = 11.73mm ø

Mont Blanc Spiral base = 15.83mm ø

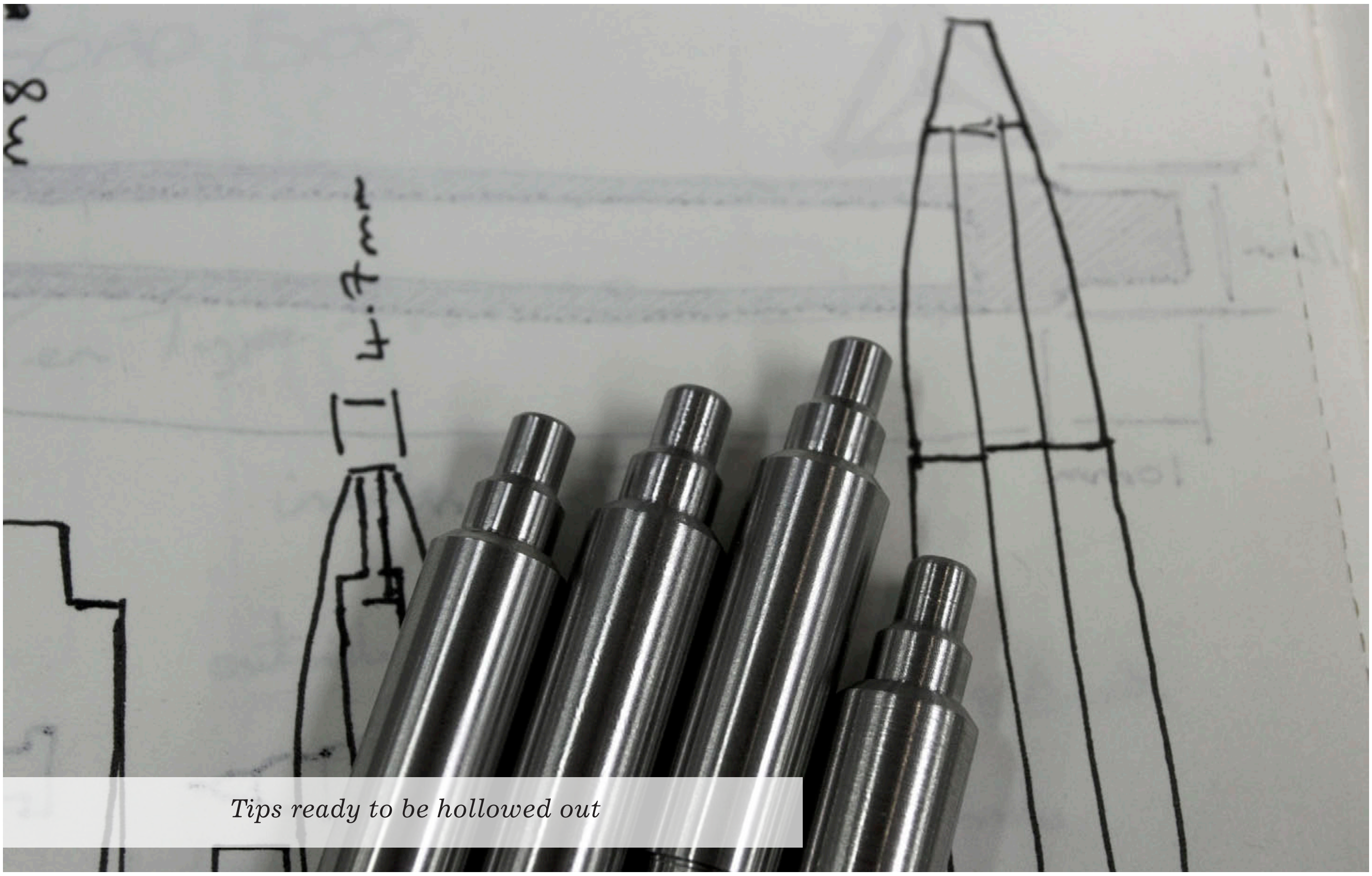
Mont Blanc Vibration base = 14.96mm ø

wall thickness = 1mm.



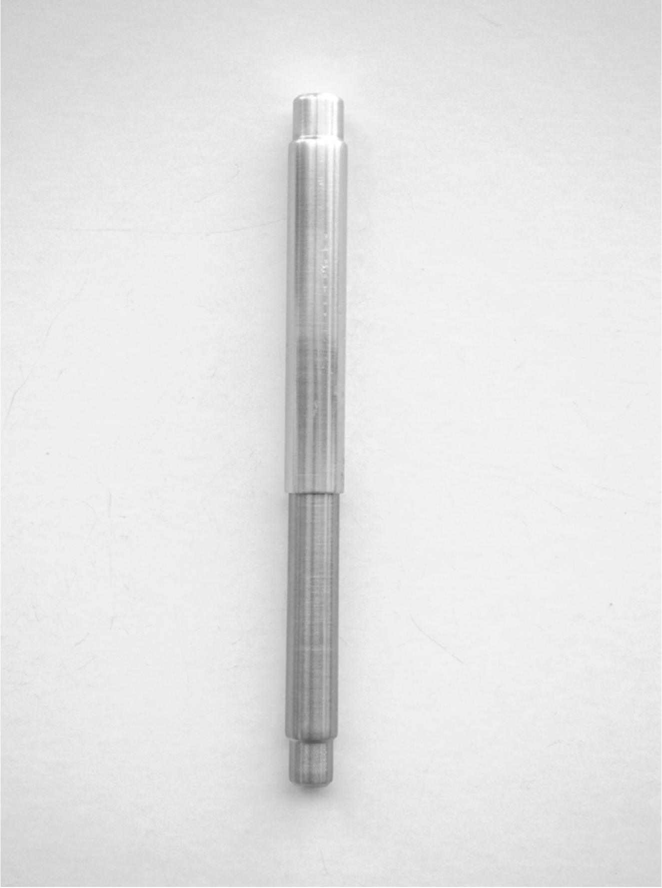


Try the Vibration Pentel
the other way.



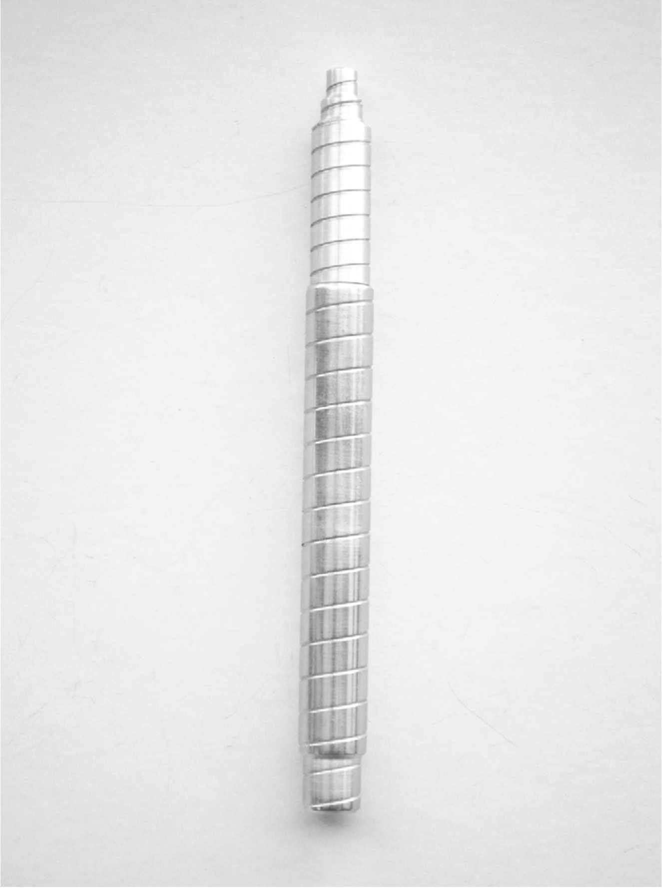
Tips ready to be hollowed out

Planning and working out measurements



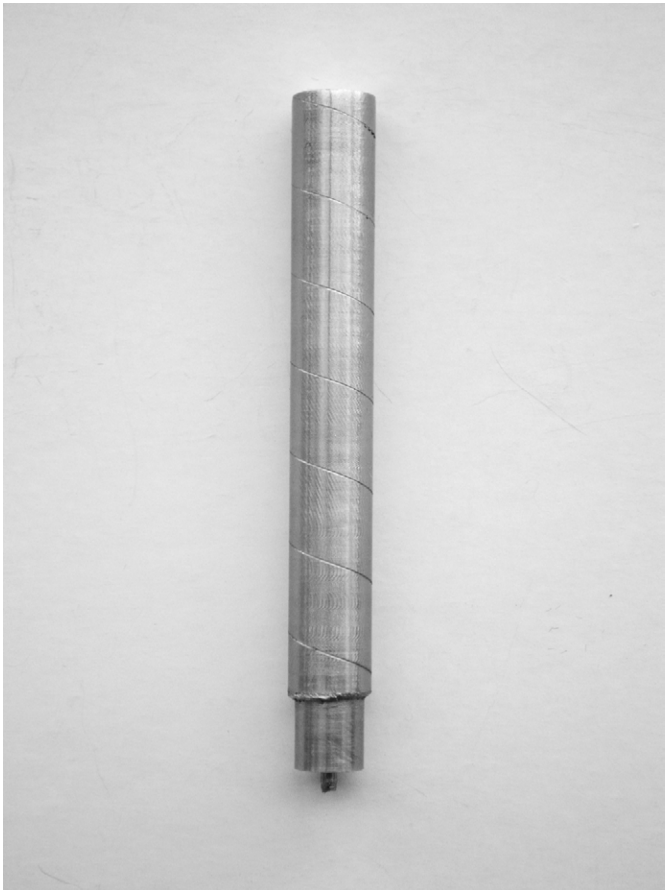
Assembled pen with Pneumatic lid

Vibration base / trouble with manual clamping

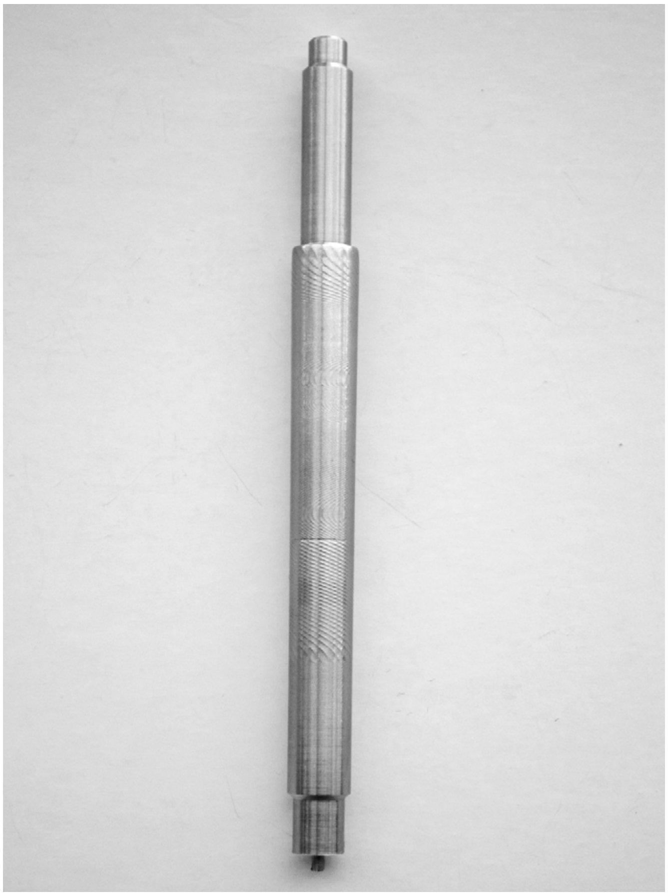


Single spiral expressed onto Pentel form

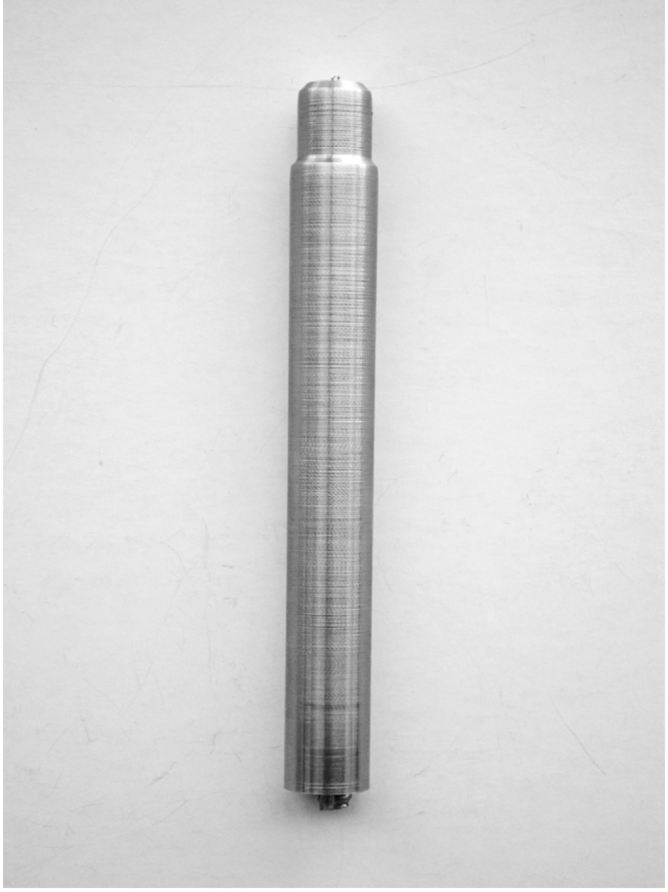
Mixing the two attributes



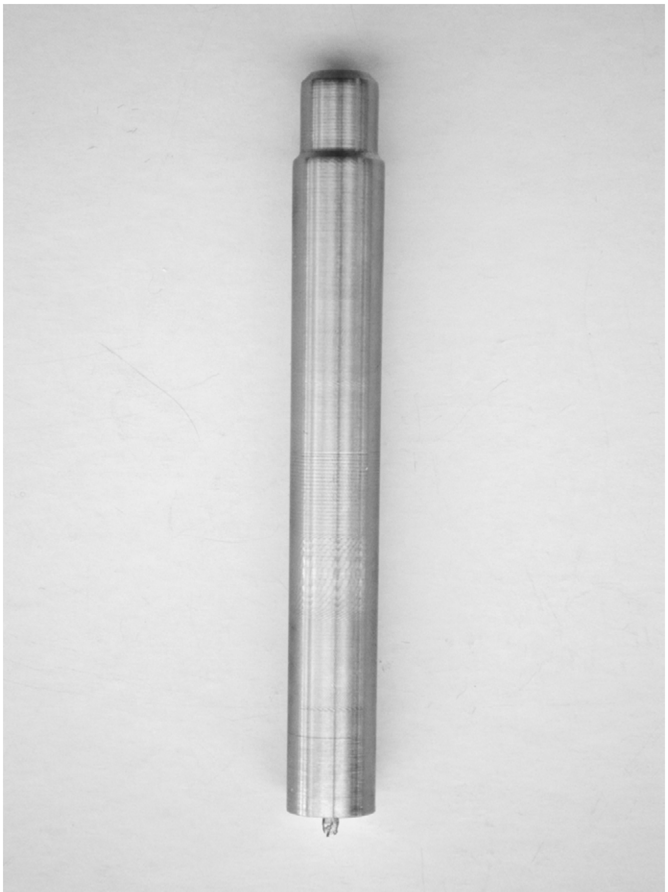
Tool breakage on chamfer / unexpected spiral



Replication of Moire success



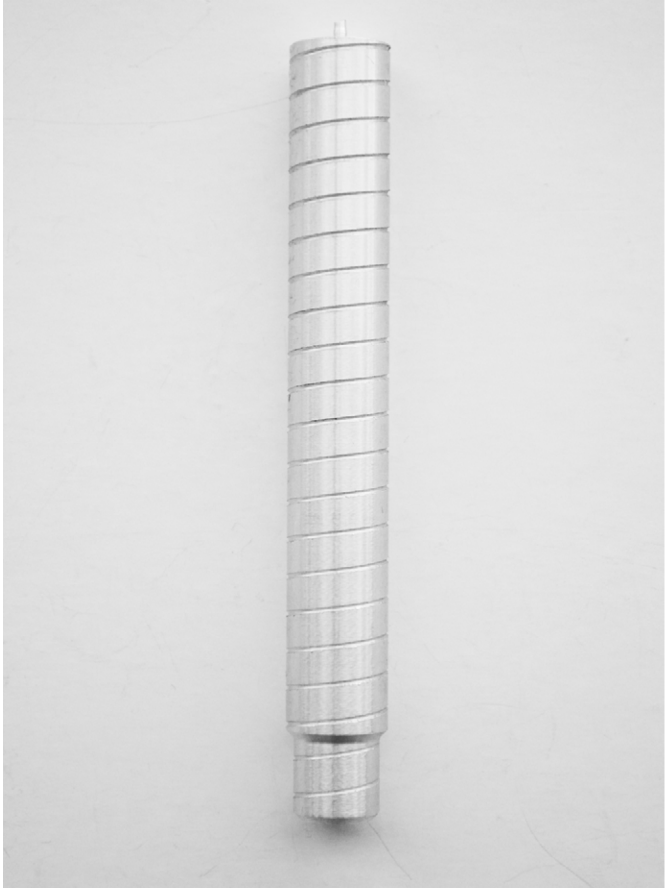
Worn tool and vibration creating consistency



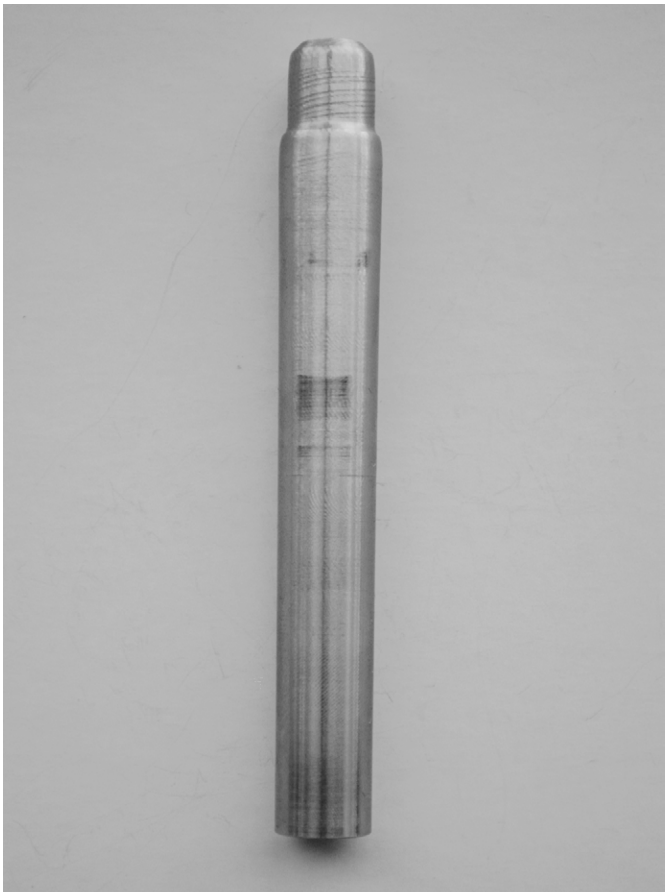
Vibration at lower speeds on stainless steel

Minimal detailing

Moire replication on pen assembly



(f) value 6.0



Lots of vibration causing a tapered profile

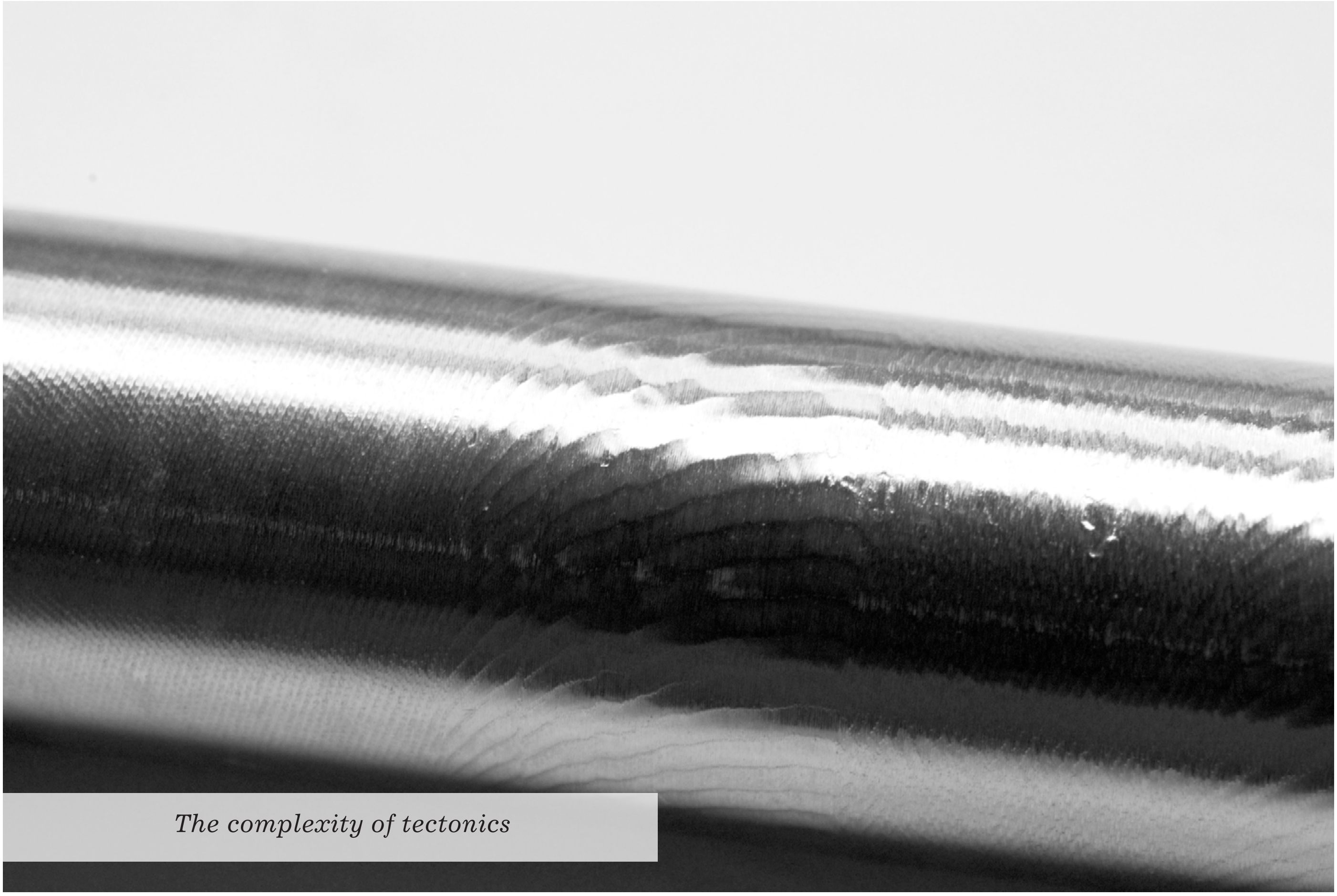
Polished finish

Close up of the accidental spiral

Same (f) and (s) value over two scales

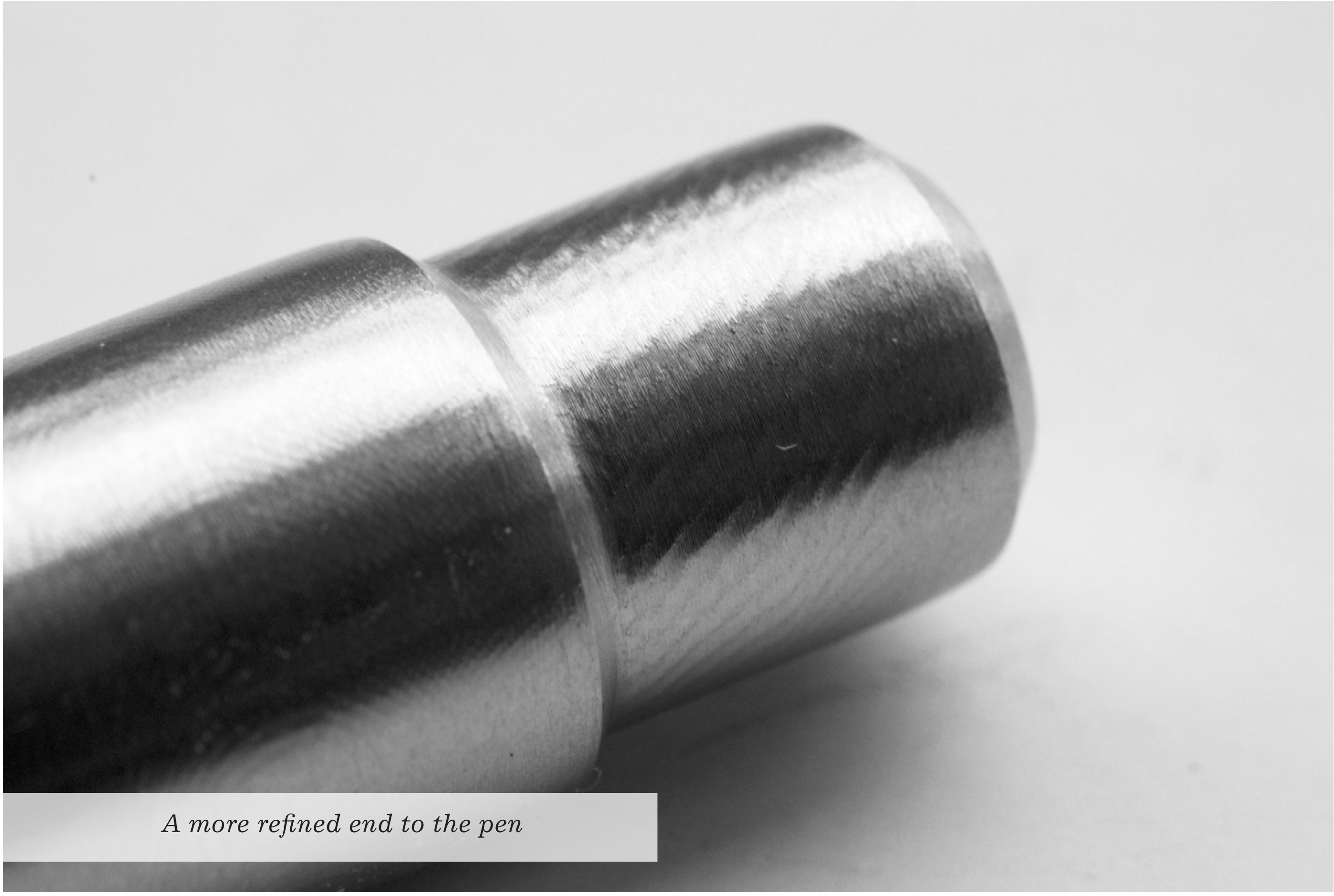
Barely visible to the eye but felt with the hand

The polished surface / smoothing down the rough

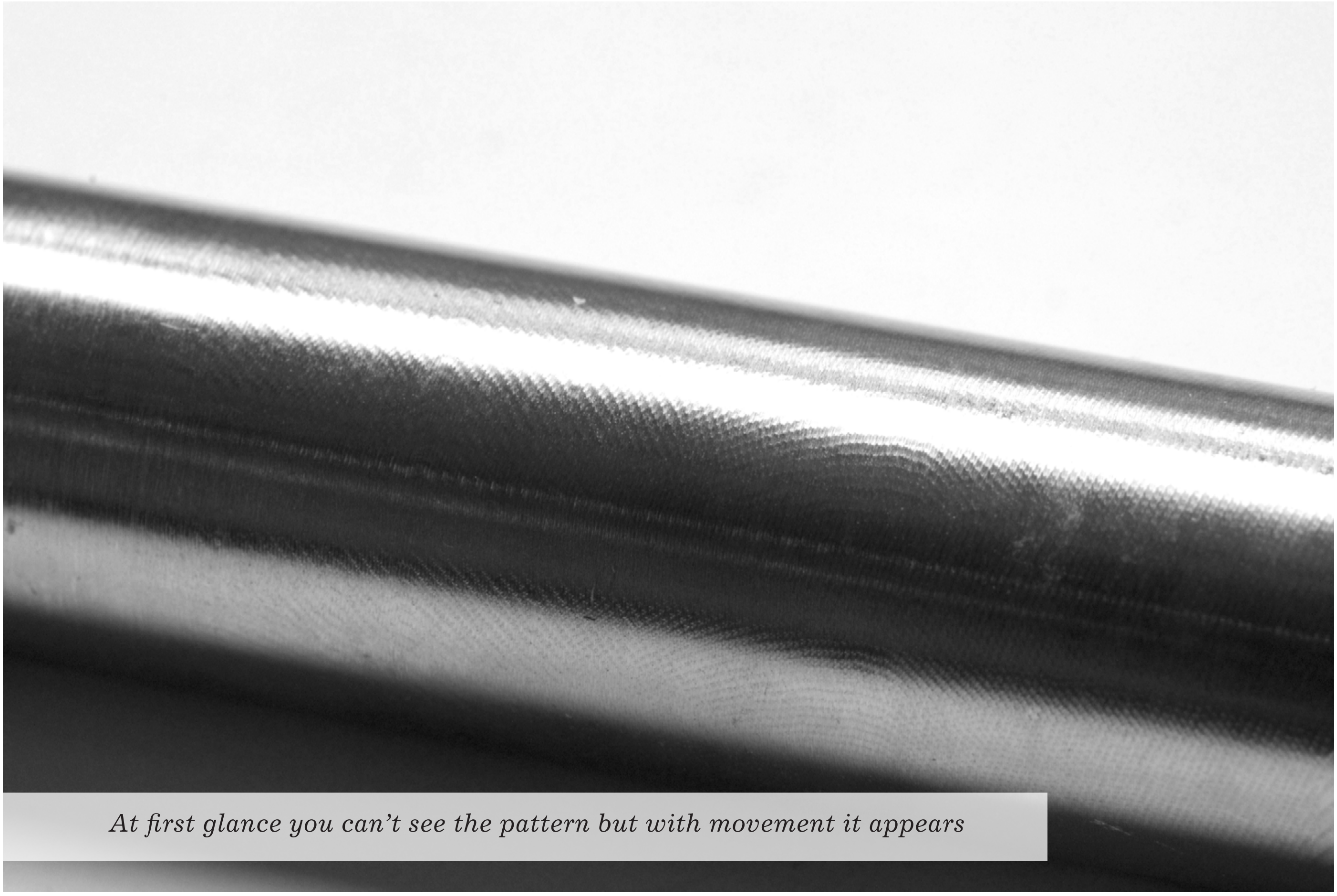


The complexity of tectonics

Sophisticated detailing

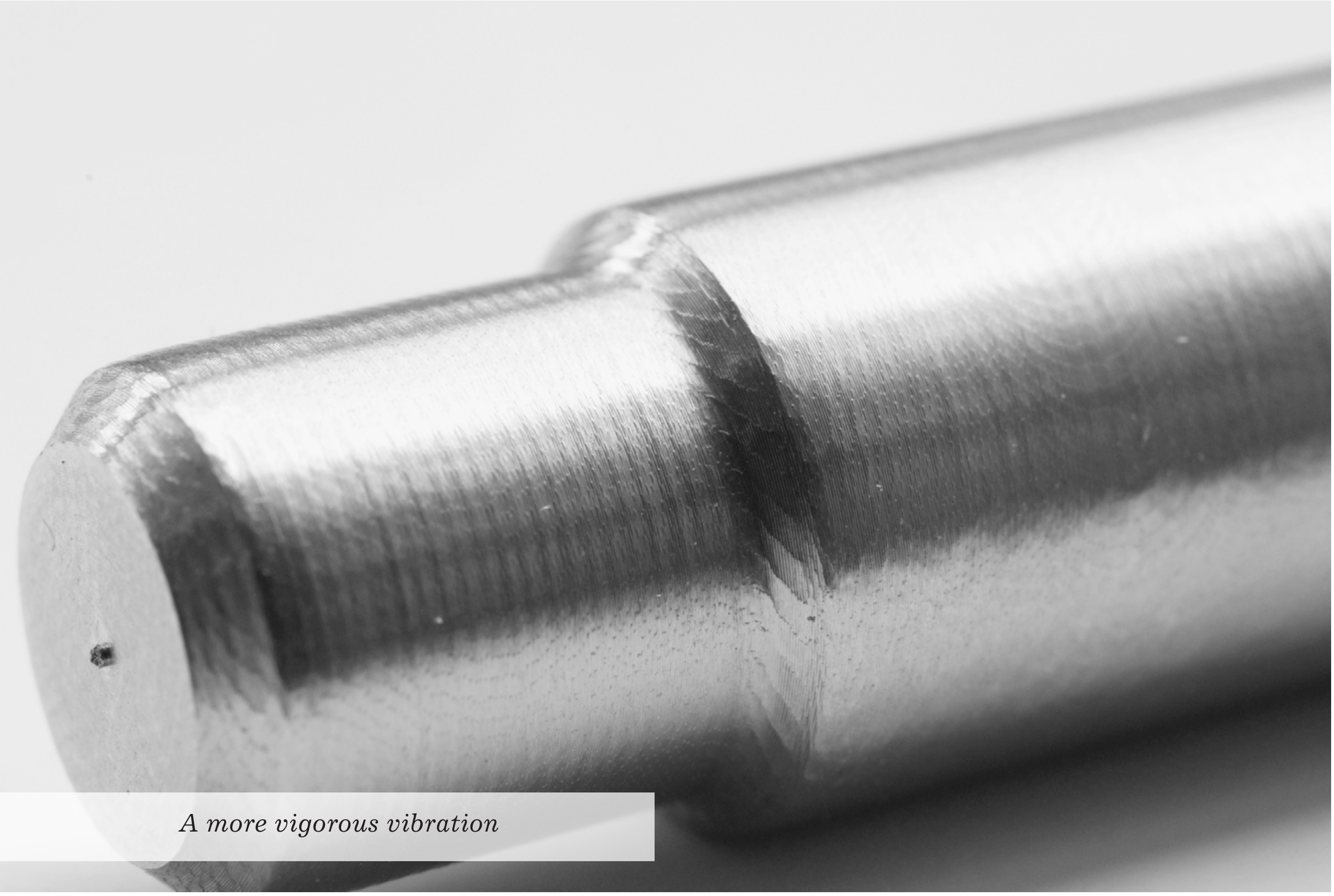


A more refined end to the pen

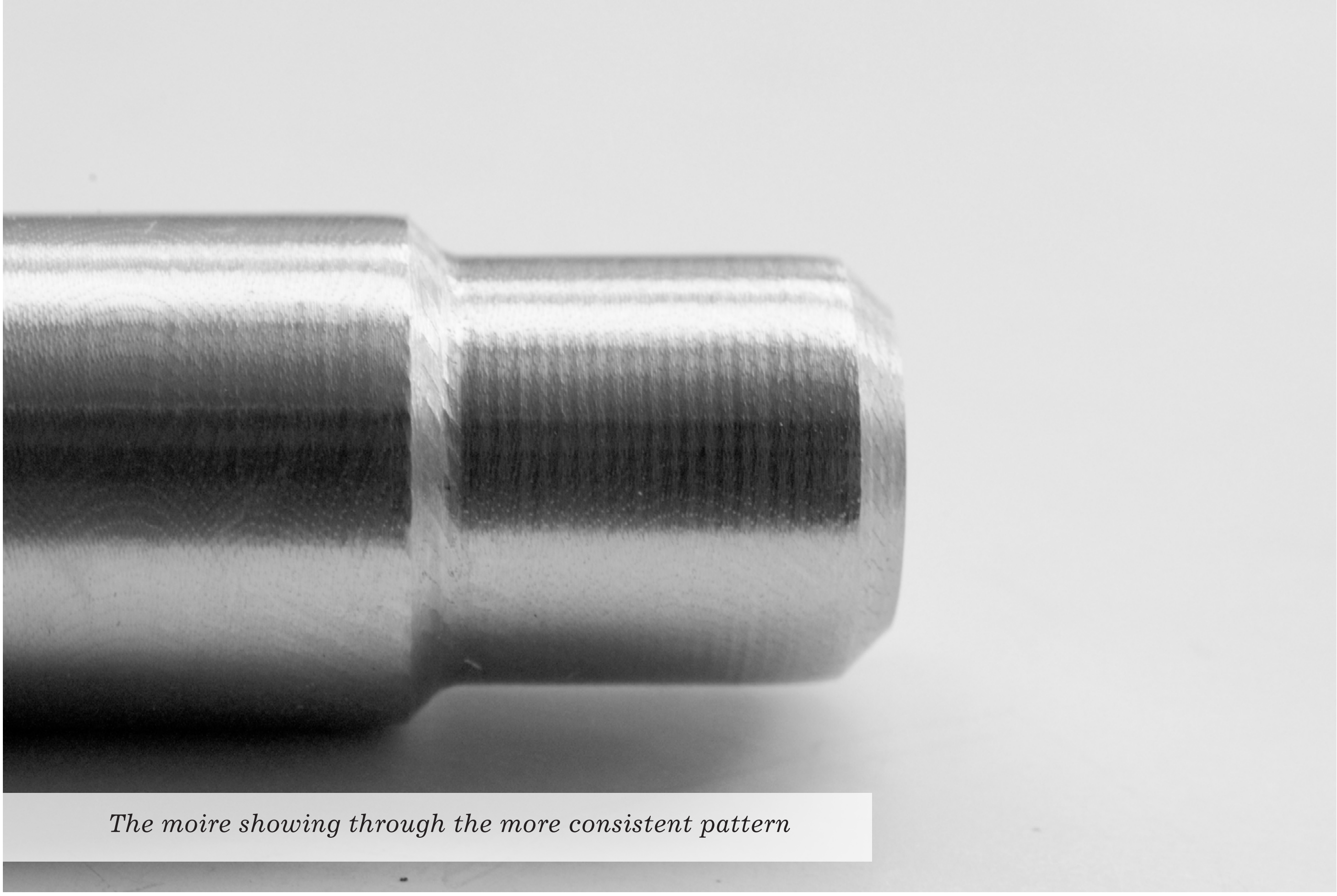


At first glance you can’t see the pattern but with movement it appears

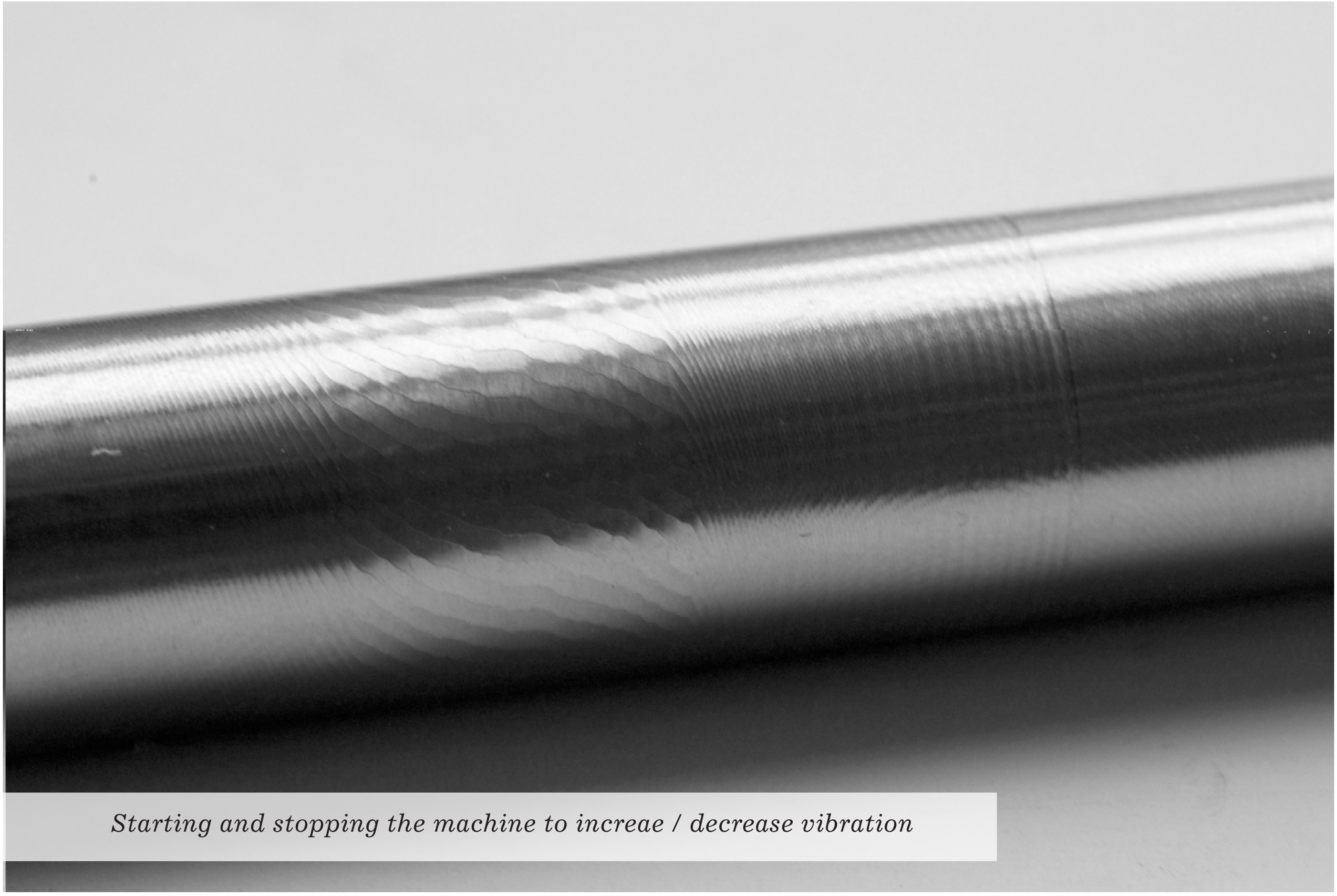
The subtle texture at the grip of the pen / tactility



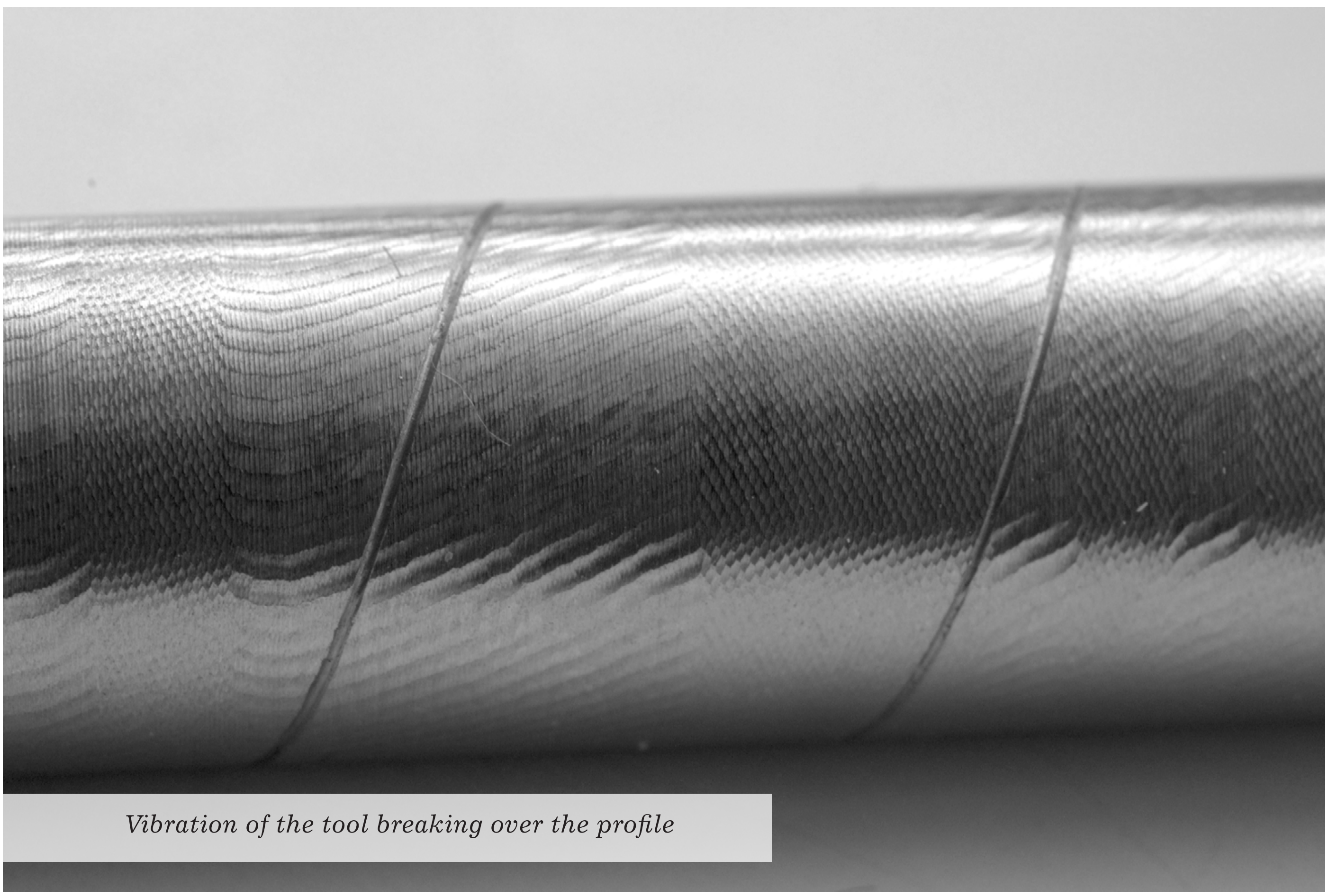
A more vigorous vibration



The moire showing through the more consistent pattern

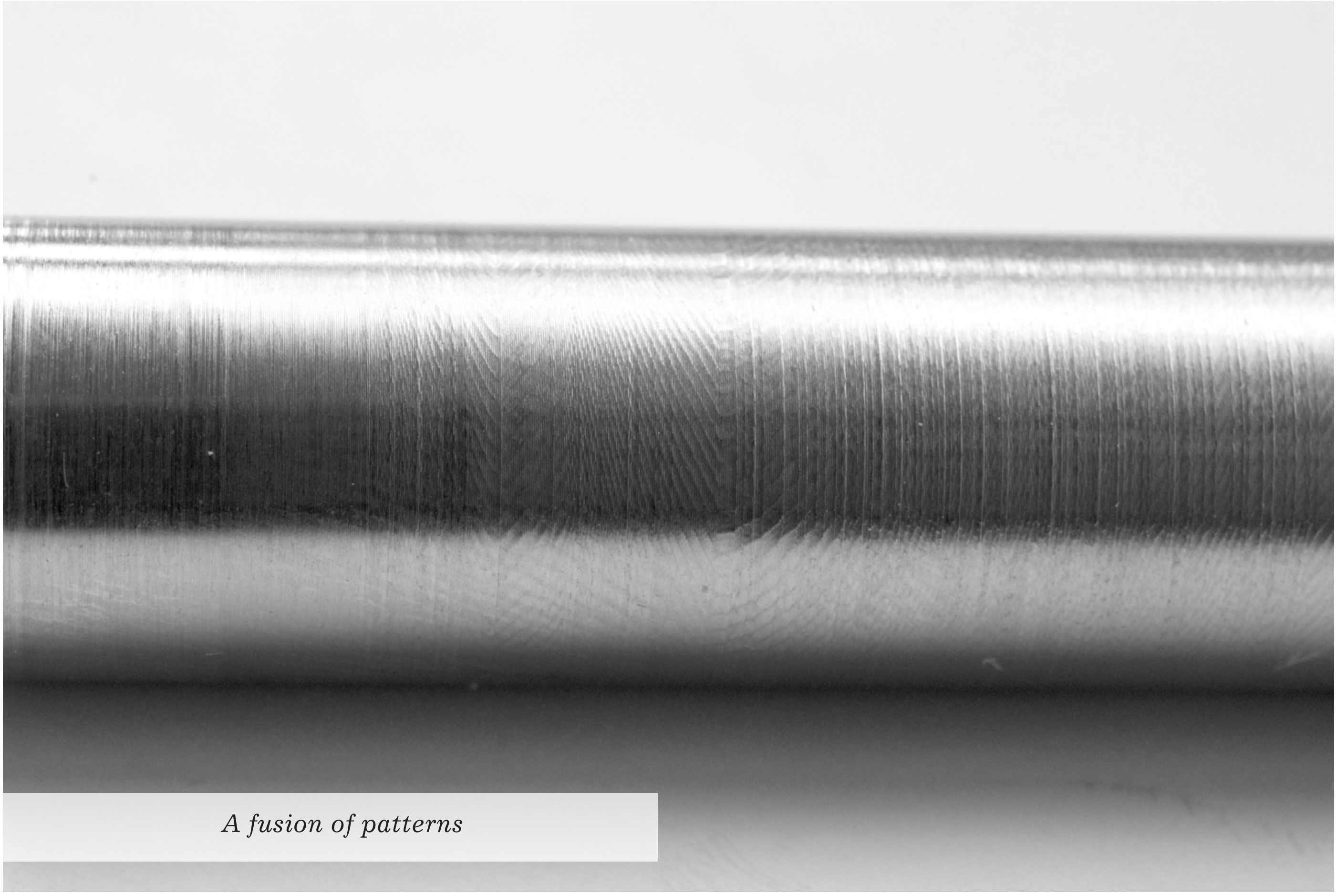


Starting and stopping the machine to increae / decrease vibration

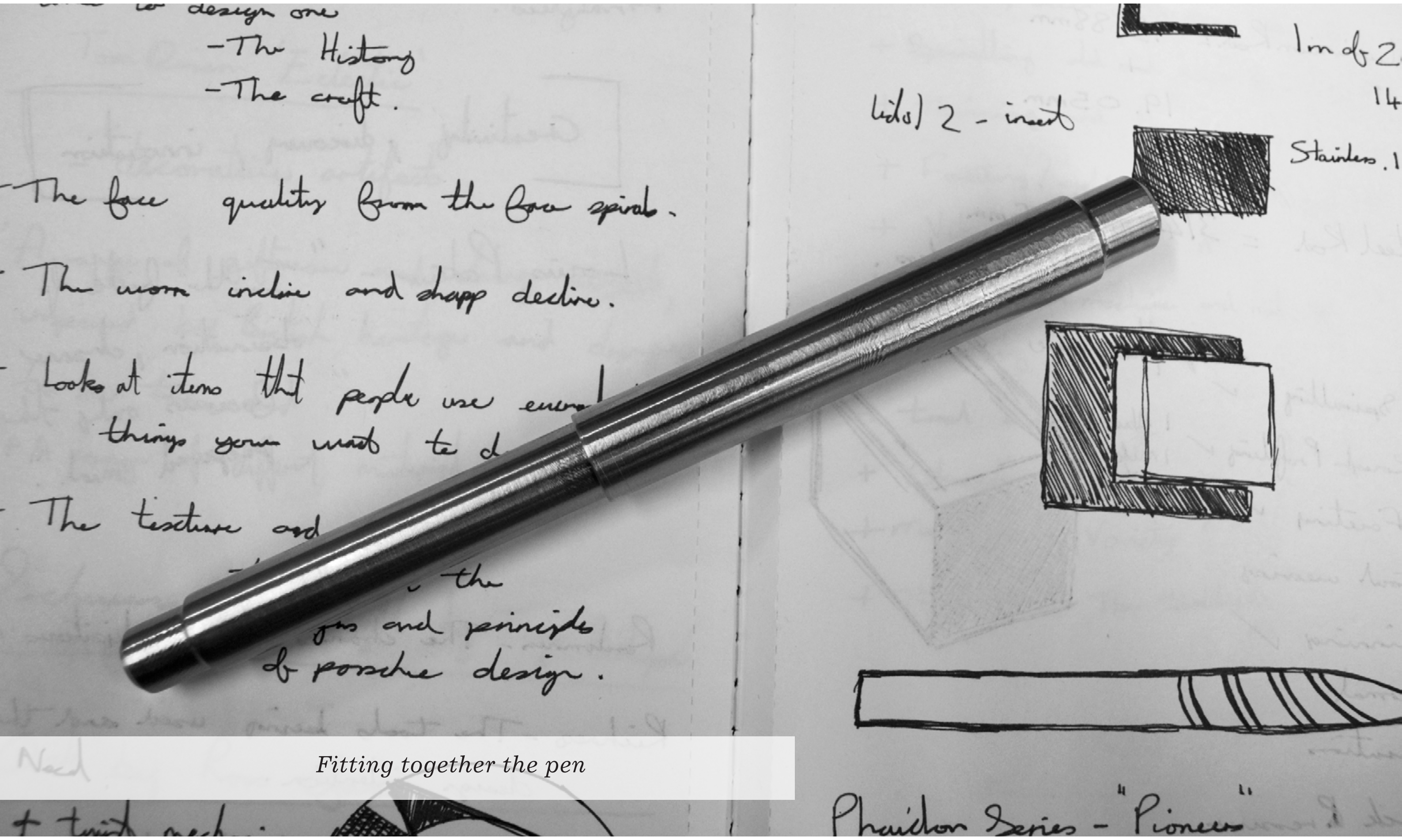


Vibration of the tool breaking over the profile

The close beauty of the 'fingerprints'



A fusion of patterns



Fitting together the pen

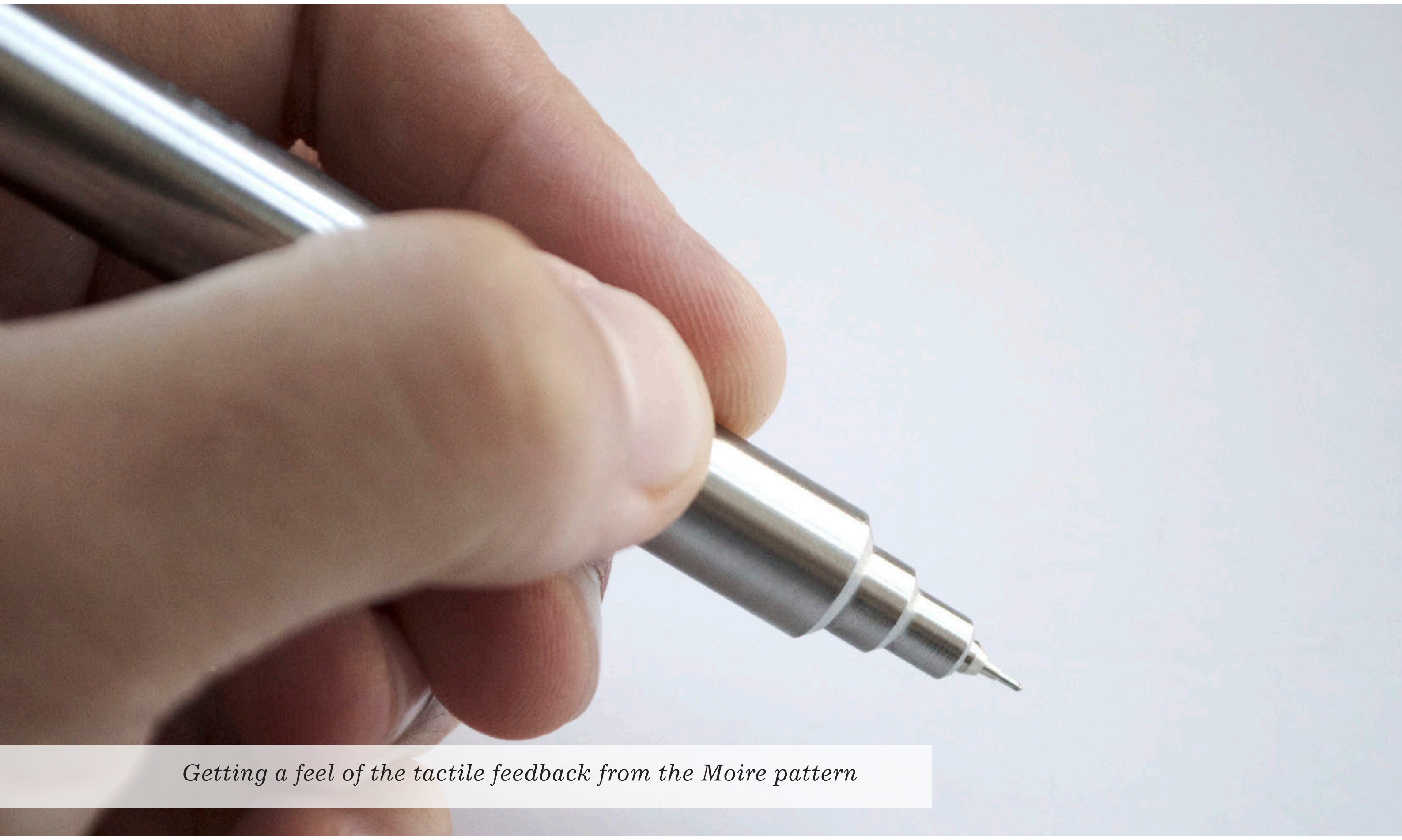
A few configurations of the pens

Configurations for the pen bases

Architectural frame for the tips

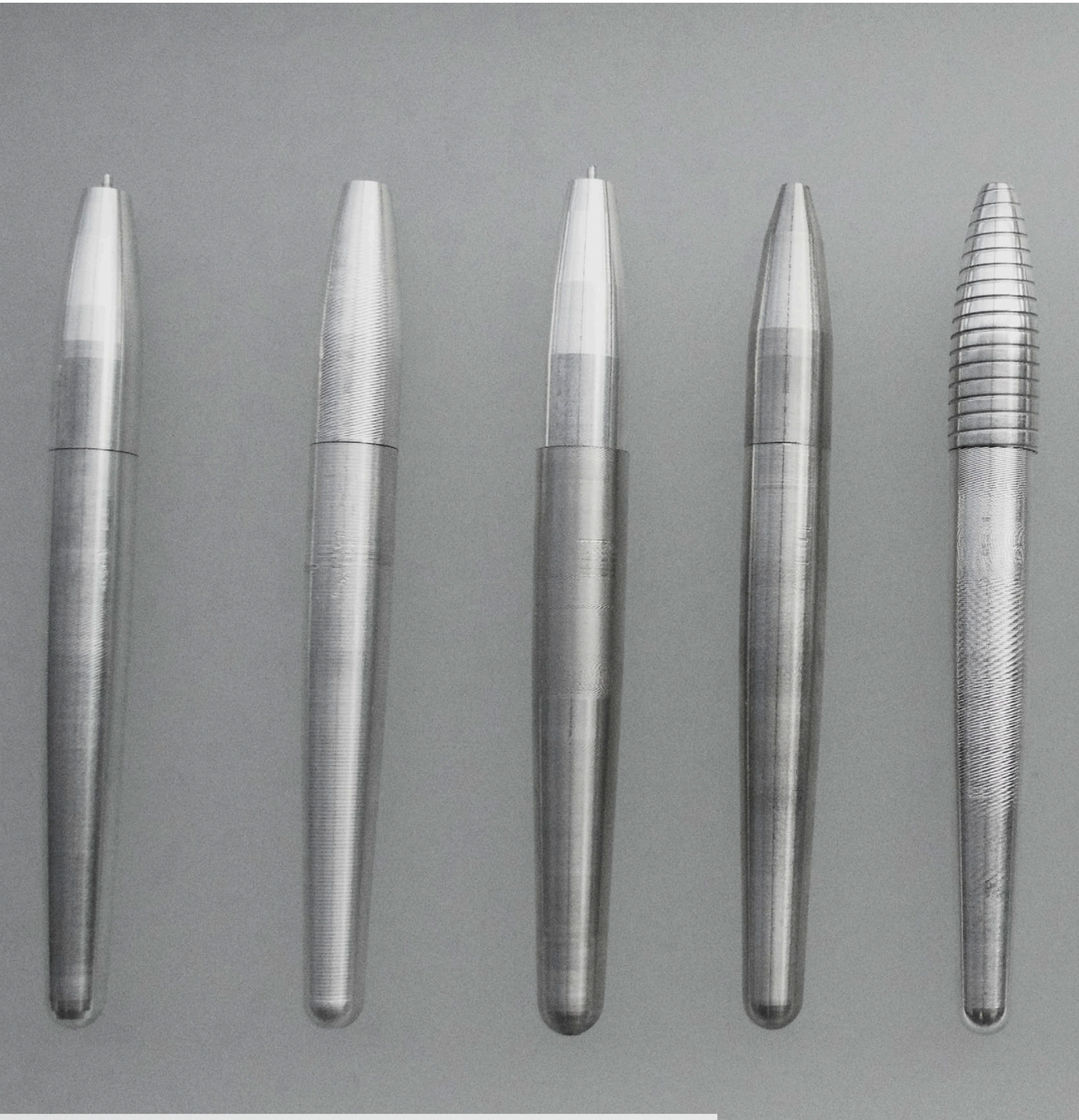
The HI-TEC-C ink fitting seemlessly into the pen

The overall sleek minimal look of the pen



Getting a feel of the tactile feedback from the Moire pattern

Tactile feedback from the spiral grip



The S-Series Range

9

conclusion

9

CONCLUSION

How can designers contrast the uniformity of CNC machining with the serendipitous nature of creativity?

This research explored the possibilities of creatively interacting with certain features of digital manufacturing processes. The designer takes on the role of the self-learner to become competent in CAD/CAM software, CNC technology and to control 3D form applying complex textures and expressions. They have learned the ability to manipulate digital surfaces and identify serendipitous qualities produced by the physical fingerprints of the machining process.

Over time the machine became more of a tool and the process, experience and even sound became second nature. With some processes the sound was the most efficient way to understand the machine. The best example coming from the creation of vibrations through a job using stainless steel and letting the machine 'sing' through the resonance of the material relating to how much was in the chuck.

Multiplying machined texture and pushing the machine itself to the limits, on occasion abused. The relation of the textures to the emotion of the object added to the richness and value sought out from the beginning, just how much it would affect the production line was unforeseen. The study spawned from the observation of mass production and the simplified surfaces for set specifications. There are many designers who use traditional manufacturing processes and push the limits of them seeing what might let them enrich it again, this case using digital processes. Taking the unexpected, to realise something insightful and make it valuable, using this philosophy to understand the tool on an engineering level and learning to intuitively identify and realise a serendipitous moment, design for it and manufacture.

“Doing something, and then only afterwards, finding out why you did it” (Tony Wilson)

Once an object has been manufactured this way, can it be replicated?

Once something amazing had been observed in the machine, an effort was made to replicate the feature, the most controllable being the spirals based on numerical changes and exact measurements that could have the same outcome mass manufactured. The simplest of changes, whether it be the length or a digit, would offer a completely different outcome. With all the other experimentation there was never a single piece that turned out identical to the one before.

The thesis was formulated to communicate through reference to objects allowing constant explorations using Cross’s model of the design process; exploration, generation, evaluation then communication. Following this model allowed the ability to design for flexibility and providing mass customisation using what was learnt from the study to create a system.

Authorship as a designer comes from defining the margin of control and randomness, whether something has become too serendipitous, compromising the crafted form, or remained banal, repeating the precision machining, and releasing any character from the object. This entire procedure can be applied to any number of objects that can be produced on a CNC machine, as the code is a universal language that translates current and future digital fabrication methods.

Finally, Digital technology has often been criticised for its smooth textures communicating a monotonous language, but as identified in ‘Paradigm Shift’, ‘Worn Out or Worn In’ and ‘Craft without Hands’ there is much room for exploration into tectonic research of digital tools. A digital outcome can be very complex and be inherent with value. The results this thesis has produced prove that the importance of tectonics, stated in ‘Tectonic to Tectonics’, is relevant in design and architecture today. Opposing the machines’ engineering, expressing the marks of the tool on an object, the imprints behaving as fingerprints left on a surface is a unique characteristic. Something that makes the end user want to experience, feel, move and use it every day. These are decorative artefacts inspired by traditions and designed to be treasured.

list of figures

LIST OF FIGURES

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Figure 18. INDN 311 3D Printing Project by James Bennett. White and Flexible Print with Copper plating. Lectured by Ross Stevens.

Figure 19. Cox, A. (2009, October 21). Ultimate Factories. Retrieved December 21, 2013, from sub5zero: http://www.sub5zero.com/ultimate-factories-porsche-911-featured-national-geographic-video/

Figure 20. Nagy, A. (2013, July 29). 18 Gorgeous Images of Job-Stealing Factory Robots. Retrieved December 21, 2013, from Gizmodo: http://www.gizmodo.com.au/2013/07/18-gorgeous-images-of-job-stealing-factory-robots/

Figure 21. Stevens, R. (2008). Worn Out or Worn In? Wellington, New Zealand: Master's Thesis, Victoria University of Wellington.

Figure 22. Emery, D. (2005). Craft without Hands. Wellington: BDes Honours Thesis. Supervisor: Professor Simon Fraser.

Figure 23. Koren, L. (1994). Wabi-sabi for Artists, Designers, Poets & Philosophers. Point Reyes, CA: Imperfect Publishing.

Figure 24. Koren, L. (1994). Wabi-sabi for Artists, Designers, Poets & Philosophers. Point Reyes, CA: Imperfect Publishing.

Figure 25. Dixon, T. (2013, June 1). Tom Dixon. Retrieved July 5, 2013, from Furniture and Lighting: https://www.tomdixon.net/

Figure 26. Dunne, A., & Raby, F. (2007, n/a n/a). Dunne and Raby. Retrieved November 23, 2012, from Technological Dream Series: http://www.dunneandraby.co.uk/content/projects/10/0

Figure 27. Goss, J. (n.d, n.d n.d). Henry Ford and the Assembly Line. Retrieved December 21, 2013, from History1900's: http://history1900s.about.com/od/1910s/a/Ford--Assembly-Line.htm

Figure 28. Lovell, S. (2011). Dieter Rams: As Little Design as Possible. New York: Phaidon Press Inc.

Figure 29. Lovell, S. (2011). Dieter Rams: As Little Design as Possible. New York: Phaidon Press Inc.

Figure 30. Koivu, A. (2012). Ronan & Erwan Bouroullec. London: Phaidon Press Ltd.

Figure 31. Koivu, A. (2012). Ronan & Erwan Bouroullec. London: Phaidon Press Ltd.

All subsequent images are photographed by the Author James Bennett

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by
James Edward Bennett