

Jacques David—and a Summary of “American and Swiss Watchmaking in 1876” with Emphasis on Interchangeability in Manufacturing

by Richard Watkins (Australia)

Background

In the middle of 2003 I translated Jacques David's *Rapport a la Societe Intercantonale des Industries du Jura sur la fabrication de l'horlogerie aux Etats-Unis*.¹ The two reports comprising this manuscript provide a detailed description of American watchmaking in 1876, a summary of the state of the Swiss industry, and recommendations to Swiss watchmakers listing changes necessary to overcome the growing threat from America at that time. Unlike the well-known opinions of Edouard Favre-Perret,² David's reports present an analysis of facts and manufacturing processes, and so provide precise information about the state of watchmaking in 1876.

[Editor's note: Please reference the last page of this article for information about Richard Watkins's translation of Jacques David's work.]

In this article I provide a brief biography of David, review the history of his manuscript, outline its contents, and examine two aspects of watchmaking described by him. Finally, I look at the concept of interchangeability in the context of the information provided by David.

Jacques David³

Jacques David was born in Switzerland in 1845. He showed a marked ability for mechanics and attended the Central School for Arts and Manufacture in Paris, where he completed his studies in 1866.

On his return to Switzerland David began training as a watchmaker, but in 1867 he was invited by his cousin Ernest Francillon to join the newly formed Longines company. Both David and Francillon were convinced of the need to manufacture watches by machinery rather than by hand, and Longines had been set up with this goal. Jacques David initially worked under a Mr. Chatelain, an experienced watchmaker-mechanic “who knows a great deal about horology and mechanics and he has an almost inexhaustible collection of ideas.” However, Chatelain fought with other workers, and in 1868, after an angry disagreement with him, David left Longines and resumed his watchmaking training. In 1869 David was persuaded to return, and he took over control of technical development at Longines, designing and building machinery.

In 1876 several of Switzerland's leading watch and tool makers attended the American Centennial Exhibition in Philadelphia, Pennsylvania. Edouard Favre-Perret was a member of the international jury for pocket watches, and Théodore Gribi led the Swiss delegation. The Longines Company sent a watch to be exhibited as one that had been entirely machine-made. At this time Jacques David had been working at Longines for about nine years, and he presumably had a major role in the development of this watch.

The Swiss delegation was shocked by the high level of American watchmaking technology, and Théodore Gribi summed up the visitors' reaction when he wrote that “we have been left behind by our New World competitors.” The general feeling was that because of

increasing American competition the Swiss watch industry was facing the most dangerous crisis it had ever experienced.

Swiss watchmakers were already aware that their industry had problems, and earlier in 1876 they had set up the Intercantonal Society of Jura Industries with the goal of protecting industrial and commercial interests in the region.⁴ When the disturbing news arrived from America, the Society agreed to send Jacques David to join Théodore Gribi in Philadelphia and carry out a study of the American watch industry.

Jacques David visited the United States from mid-August to November 1876 and, after attending the Philadelphia Exhibition, he toured American factories with Théodore Gribi.

Following their return from America, Edouard Favre-Perret and Théodore Gribi spoke openly about what they had seen, in an attempt to stir the Swiss watchmakers into action.

In contrast, when Jacques David returned to Switzerland in November, he wrote a long, detailed, confidential report that was presented to the Intercantonal Society on January 22, 1877. At this meeting the Society agreed with David's request that his report not be released to the press or public. Less than two months later, David presented a second report to the Society. In this one he aggressively attacked the Swiss watchmaking industry's complacency and lack of action over the previous months and predicted the end of watchmaking in Switzerland if the recommendations contained in his first report were not acted upon promptly.

In lieu of publishing David's reports, the Intercantonal Society prepared some eight manuscript copies for private distribution to its members. Few details of what happened thereafter to these copies are known.⁵

But, although his reports disappeared from view, all indications are that David's warnings were heeded. As Jean-Marc Barrelet wrote:

Jacques David, Théodore Gribi and the others were the principal agents for the modernization of the Swiss watch industry. With courage and perseverance they convinced the tardy of the need for mechanization and the need to persuade the watchmaking world to move from the bench into the factory.

In later life David continued to work for Longines. He became the company's director in 1880 and over the years was involved in many horological organizations in Switzerland.

We are extremely fortunate that the Longines Watch Company found a copy of David's reports. In 1992, on the occasion of the company's 125th anniversary and 115 years after the manuscript had been written and suppressed, Longines published a facsimile of the document.

From this history we can reasonably conclude that Jacques David, with about ten years of experience in watch and machine making at Longines, was in a position to make a competent, correct assessment of the state of American watchmaking. Consequently we can be confident that his reports provide an accurate description of watchmaking by machinery in 1876.

The Reports

Jacques David's first report comprises 108 handwritten foolscap pages with in-text illustrations, and eight hand-drawn plates containing diagrams of tools. After an introduction it is divided into seven sections:

1. *Number and Importance of American Factories.* This provides a brief history of watchmaking factories in the United States and their status in 1876. The emphasis is on the Waltham and Elgin companies.

2. *Financial Conditions.* An assessment of the cost of setting up, tooling, and running a watch factory. Included is an estimate of the cost of manufacturing a watch based on annual expenditures. There is a discussion of general financial conditions and the likelihood that American factories could manufacture watches more cheaply than Swiss firms.

3. *Interior Organization.* This describes the administrative organization of the factories; their regulations, principal officers, departments, accounting, stores, pay-day procedures, notebooks, apprentices, and general conditions. It includes information on rates of pay, female workers, and housing.

4. *Production Quantity and Quality.* An assessment of the total annual output of American factories and its distribution amongst models and grades. There are remarks on price competition, patents, and the rating of American movements.

5. *Sales.* A brief section on distribution methods, exports, and advertising.

6. *Methods of Manufacture.* This section is the main part of the report. It begins with the general principles underlying American manufacture and the focus on machine design and construction. Then the process of manufacturing a watch (probably largely based on David's observations at the Waltham factory) is described step-by-step. This is done by detailing the work done in each of the main workshops: cutting, steel, plate and screw, the motion room, escapements, jewel making, jewel setting, preliminary assembly, finishing, balances, dials, and cases.

7. *Conclusions.* David begins with an assessment of the Swiss watch industry, arguing that Swiss manufacture would be destroyed by American exports unless immediate action was taken. He then specifies ten recommendations for restructuring the Swiss industry, including adoption of American methods, education, patents, and standards.

Some of the information in the first six sections has been available from other authors.⁶ David's analysis is nevertheless important because it provides a coherent, contemporary examination. The last section is fascinating, being a very clear assessment of the state of the Swiss watchmaking industry and presenting recommendations that summarize the ensuing development of that industry.

The second report, presented in March 1877, consists of only 12 pages. It is an aggressive attack on the attitude with which Swiss makers received (and ignored) his first report. As a focus, David refers to a letter from A. Lange & Sohne and demonstrates that the arguments in this letter, and those expressed by other people, were wrong. He provides further evidence that the American factories were in the process of taking over all of Switzerland's markets, and that Swiss watch sales were dropping dramatically. David concludes by reasserting that the Swiss industry had to immediately adopt American organizational and machine manufacturing techniques in order to survive.

Because the American manufacturers cooperated with their Swiss guests, David's reports on their technology cannot be viewed as industrial espionage. Even so, the suppression by the Society of the reports was due to fears that the American companies would become uncooperative if they realized they were helping their main competitor.

At the start of Section 6 in the first report, David lists seven general principles under which American manufacturers operated. The first three principles are:

1. Make everything with machines that can be done so.

2. To obtain economy and uniformity, avoid the intervention of handwork and suppress it wherever possible.

3. To obtain complete uniformity, so that all parts are interchangeable with the aims of facilitating move-

ment assembly and reducing the work of repairers to a minimum.

It is clear that for David these are the most important aspects of the American system, and his report focuses on interchangeability. In Section 2 of his first report, he shows that about half of the cost of making a movement is labor, a point the watch factory managements were well aware of. These three principles simply state that to reduce costs, labor must be reduced; and to reduce labor, manufacturing must be done by machines, and assembly should simply be the mindless insertion of interchangeable parts.

Although most of the processes described by David relate to interchangeability or lack of it, some other aspects of manufacturing are also examined. For example, one of the most interesting tools described by David is for making epicycloid wheel and pinion cutters.⁷

In this paper I will examine two tools described in Section 6 of the first report. The first is the method used to manufacture interchangeable plates. The second is the way in which American manufacturers overcame a lack of interchangeability.

Interchangeable Parts—Platemaking

In order to understand some of David's statements, it is necessary to be aware of his view of interchangeability.

Interchangeability can be defined in various ways. One approach is exemplified by Hoke, who says "interchangeability meant different things to different manufacturers," and that final adjustments can be and were made to "interchangeable" parts.⁸ Thus he argues, with regard to Waltham: "Watches were also interchangeable within the confines of this new definition of interchangeable. Most parts . . . were completely and fully interchangeable, while some parts were interchangeable until assembly. . . ." In contrast, Landes provides a strict definition of interchangeability: "the ability to choose any part in a pile and insert it in its place, where it functions without further adjustment or treatment."⁹

David's view of interchangeability matches the strict definition. That is, if a part needs further adjustment he did not regard it to be interchangeable.

The basic steps for making interchangeable plates are relatively simple, and David glosses over them.¹⁰ The plates were purchased from the Scoville Brass works and then dressed and turned. The reference points for all later operations were the three holes for the dial feet. These holes, as well as the pillar holes, were made using a punch. At the same time "points" marking pivot holes were made; these would be drilled or opened for jewels later. In addition, at later stages many other features had to be accurately cut, including recesses and holes for steady pins and jewel screws.

The processes involved in making recesses and holes are, in principle, straightforward and David says little about them. But ensuring they are placed and sized accurately is not. David's explanation follows:

To bore the other smaller holes exactly in their places (like those for chaton screws, steady pins and screws for cocks, balance spring studs, etc.) the plate is locked in a plate gauge where it is positioned by the holes which have just been cut. One face of this plate gauge carries holes furnished with hard steel canons. These canons are the exact sizes and in the exact positions which the holes must occupy. They are not only used to guide the drill bit, but also to measure it. The other face of the plate gauge has larger holes to let the drilling shards escape.

Hoke provides a fuller explanation of the method. The plate gauges or jigs produced from masters were clamped onto watch plates. Each plate then passed through a number of drilling stations where workers operated three-spindle drill presses. At each station the holes corresponding to the available drill sizes were drilled and the plate then passed on to the next station, with its gauge attached, where further holes were drilled.

Central to drilling plates accurately is the ability to produce a number of precise *plate gauges* from the original caliber model. David describes this operation in detail:

*The master plates for the pillar plates, for turning, drilling, jewel setting, etc., must be made very exactly so that these parts **go together without any need to alter them.**¹² To arrive at this result, an eccentric platform is used for the construction of the master plates (see Figure 1). This platform is composed of a large disc **A** in which is adjusted an eccentric disc **B**. In this disc **B** is another disc **C**. These three discs can turn one within the other, held by strong friction, and they can be locked in position by two pairs of clamps **DD** and **D'D'**. The interior of disc **C** has a large recess **E** in which the master plate to be constructed can be adjusted. These master plates are, moreover, locked in this recess by 2 pins **pp'** so that they can occupy only one position in the disc **C**. The master plates in **E** and the points **pp'** are made identical one with another using suitable gauges. In consequence of the arrangement of the discs **A**, **B**, and **C**, any point on the disc **C** can be brought to the center of the platform **A**.*

*So when there is a master adjusted exactly in the recess of **C**, each hole of this gauge is successively centered, and for each hole a reference mark is traced between discs **A** and **B** and another reference mark between **B** and **C**. For each center a hole is bored on the edge of the disc **C** which precisely fixes it to disc **A** by a carefully turned pin. The holes of the master plate, the reference marks between the discs and the holes for the fixing pins are all numbered with the same figure. This*

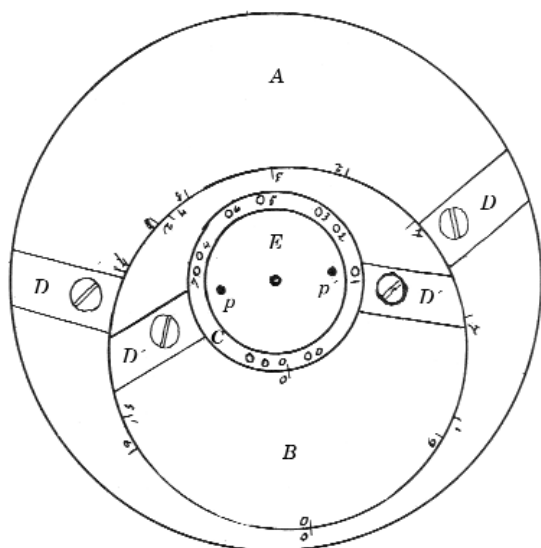


Figure 1.

delicate and extremely time consuming work being finished, there is now the means of transferring, in a rigorously exact way, the points of the gauge in their correct relative positions to any plate which is carefully adjusted in the recess of the disc C.

David gives no indication of the effectiveness of the master plate tool described above, from which we can conclude that plates were manufactured to sufficiently small tolerances to be interchangeable.¹³

Unique Parts—The Record

As I have noted, David's concept of interchangeability matches the strict definition given above. An example of this is his description of the manufacturing of barrel arbors: "It is admitted that any tempered and polished steel part cannot be absolutely in conformity with a specification. The variations are extremely small, and the workmen are given permission not to be delayed by small irregularities in the barrel arbors." That is, it is far cheaper and faster to accept barrel arbors that are not interchangeable and adjust the barrel holes to suit. As barrels and their arbors should never need replacing during the life of a watch (perhaps a rash assumption!), the lack of interchangeability only affected manufacturing. This problem was solved by the ubiquitous *jewelling calliper rest*, the barrel holes being enlarged to suit each particular arbor.¹⁴

The same problem arose with all other pivots. Despite using automatic or semiautomatic pivoting machines, pivots varied in both diameter and length and these variations exceeded acceptable tolerances. These variations would have been due largely to hardening and tempering after pivoting and the following smoothing and polishing using wigwags.¹⁵

Not only were pivots unique; jewel holes were also not interchangeable. Although jewels were cut to effectively identical external dimensions, the hole itself var-

ied beyond acceptable tolerances. All jewel holes were measured and the jewels sorted and stored by hole size.

David rightly regarded pivot variation as a very important problem and he spent much space examining the American solution. To quote the main part in his report:

When the barrel and the center wheel have been planted, all the other mobiles are placed in the movement boxes (that is to say, the third wheel, the fourth or seconds wheel, the escape wheel, the pallet and lever, and the balance).

Then there is a special operation completely unique to the American factories and which has had a great influence on the success that their movements have obtained at this moment. This operation is called the Record. Recording consists of noting in a table the diameters of the two pivots of the five mobiles indicated above, and the lengths of these pivots. This measuring is done very carefully for each part in the movement box and noted with the movement number. When that is done, the necessary jewels are put in each box, in agreement with the list of pivot sizes which has been just made. This last operation is simple, since all the jewels and chatons are sorted according to their hole size. The jewels are naturally selected in order to have suitable side play on each pivot.

Even if a movement is to have only top plate jewels, or some mobiles are not to be jewelled at all, the sizes of all the pivots are noted, and a female worker passes a numbered broach through the holes which are not to be jewelled. These holes do not need any retouching.

Jewel setting is done exactly according to the specifications in the Record, which the jewel setter has with him to check in case of any doubt.

It should be realized that if a mobile needs to be replaced later it is sufficient to send the movement number to the factory to receive an exactly similar mobile. The Record is also useful if there is an accident with a movement box before the chatons are fixed. The woman who specialises in these operations quickly sorts the mixed chatons and puts them back in their places. Repairs which occur during work on the movement and which involve changing a mobile must refer to the Record. This requirement necessitates a special control of repairs.

The Record also notes the size of the impulse pin, or the size of the fork notch, so that a replacement lever or roller can be sent for with the same ease as with pivoted mobiles.

The record sheet in each movement box, after having been in circulation in the workshops during the course of manufacture, arrives at the office where it is preserved in the event of a request for a repair part from outside.

Two inescapable conclusions can be drawn from this description:

1. Irrespective of the view of interchangeability adopted, these parts were not interchangeable with respect to repairs made outside the factory after the movements had been sold.

2. American watchmakers regarded jewels and pivots as unique and not interchangeable. Indeed, the Record shows that watch manufacturers regarded each watch as unique, and each watch required a precise, unique description.

David places considerable stress on the advantages of the American watch in this regard: "From the point of view of repairing, the advantage is even larger and the watch merchant has notable economies by buying a new piece from the factory instead of trying to put a defective part in order. . . . The merchant can dispense with maintaining a repair shop, which is necessary for Swiss watches."

Thus, although in 1876 American watches were not made from fully interchangeable parts, the Record enabled the purchaser and repairer to treat them as though they were. Hoke quotes a *Scientific American* advertisement of 1884 saying that Waltham kept "accurate records of all its watches" and that "the owner need only send on the number of the movement to enable the factory to supply an exact duplicate" of a part. The implication was that the movement number was only needed to pick a part for the correct caliber, rather than to enable a noninterchangeable part to be made.

Pivots and Jewels

As jewels and pivots could not be manufactured interchangeably, the watch factories had to develop specific and sophisticated techniques to overcome this problem. David provides a very clear description of the method used: *The mobile pivots do not have exactly the same length, either because of turning or as a result of polishing.*¹⁶ *These errors are rectified in the following way, by an operation as delicate as it is ingenious.*

The chatons of the top plate are set up and the top plate is mounted on the pillar plate.

The difference between pivot lengths is allowed for by the chaton of the pillar plate. A shoulder is turned on it in order to insert it further into the plate if the mobile pivots are short and to insert it less if the mobile it must receive has long pivots. To be turned in this way, the chaton is gripped in a chuck to the left of the slide rest (shown in Figure 3).

A is the left edge of the graver which turns the shoulder of the chaton. B is a center which rests against the jewel. The distance between A and B varies according to the lengths of the mobile's pivots. The movement is placed between the centers e and g, with the top plate resting against g. The center f rests against the flat face of the top plate jewel; for that to happen f passes through the hole in the pillar plate. In the same way the center e rests on the shoulder made for the chaton in the pillar plate hole. Thus the distance between the ends of e and f is the distance of the planting of the two jewels.

If a correctly pivoted (standard) mobile is put between c and d, the position of the graver can be adjusted with respect to the point B in such a way that the graver A finds the edge of the chaton slightly higher than the jewel (as indicated in Figure 2). The difference between m and n will give end play to the mobile.

This first adjustment of the relative positions of A and B being done, it should be understood that if a mobile is introduced which has long pivots, the point B will overlap the graver A and the shoulder turning will be shallower than with the correctly pivoted mobile. This chaton when put in place will descend into the hole less than the normal chaton.

If, on the contrary, a mobile is introduced which

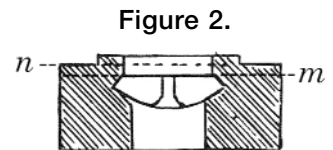


Figure 2.

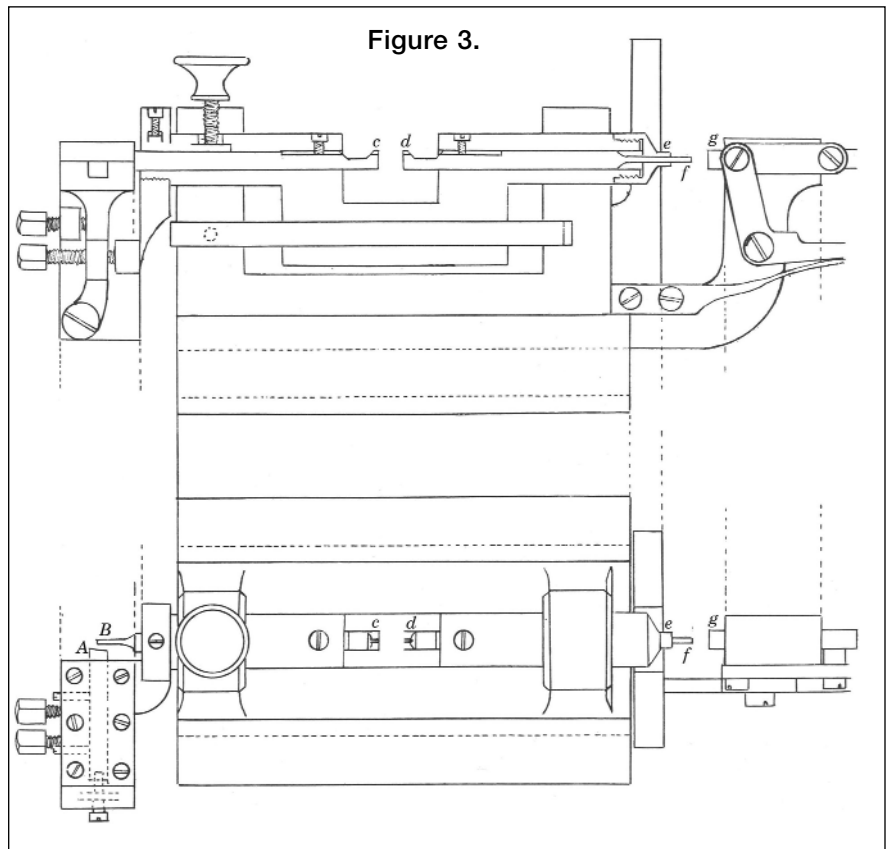


Figure 3.

has pivots shorter than the standard, the point **B** will be held behind the graver and the graver will remove more material from the chaton. The chaton, when set up in the plate, will descend farther than the normal chaton and the mobile will not have too much end play, even though its pivots are too short. The shoulders of all the chatons which go in the pillar plate are turned in this manner.¹⁷

If there are no jewels, which happens in ordinary movements, end play is given by placing the wheels and testing them. The plate is recessed more or less to suit, using a hand-held or preferably a fixed graver.

One interesting consequence of this explanation is that we can be reasonably sure that many of the gauges illustrated in Hoke and other books have nothing to do with interchangeability; they were used to create the Record and so compensate for a lack of interchangeability.

Interchangeability

I shall begin by examining the strict definition of interchangeability previously given, which is in accord with David's approach.

The problem of interchangeability only arises when components that must fit together are mass-produced, so that a complete item is constructed by putting together a random selection of such parts. It does not arise when an item consists of only one component or when the components for one item are manufactured entirely separately from the components for another similar item. Although in both of these cases the parts might be made precisely enough to be "interchangeable," interchangeability is unnecessary and has no effect on production or the quality of the items produced. Indeed, the mass production of items by machinery necessarily produces very similar, potentially interchangeable items, irrespective of whether interchangeability is a goal. However, most manufactured items, even as trivial as a spade, involve fitting parts together (the blade and handle), and the question of interchangeability occurs.

As a simple case, consider two circular parts that must fit together, with one inside the other; for example, a pivot and its corresponding hole in a watch plate.

No matter how good the manufacturing process is, pivots and holes will vary in diameter. In the mass production of a piece some variations in size and shape are inevitable, due to play in the machines, wear of cutting tools, and changes in the size, shape, and consistency of the raw material. For example, small changes in the thickness of wire can affect where and how it is gripped in a lathe chuck and seriously affect the size of the finished piece (which is why the invention of the slide spindle by Charles Mosely was so important). Consequently a part is defined to be *interchangeable* with another part if both lie within prescribed *toler-*

ances. That is, if the diameter of a pivot varies between $D+d$ and $D-d$, and the diameter of the hole varies between $H+h$ and $H-h$, then pivots and holes are interchangeable if and only if:

1. The largest pivot is smaller than the smallest hole, $D+d < H-h$, and

2. The range of *side shakes* from $(H-h)-(D+d)$ (the largest pivot in the smallest hole) to $(H+h)-(D-d)$ (the smallest pivot in the largest hole) is acceptable.

So in this instance interchangeability depends on being able to create a manufacturing process that ensures the values of d and h do not exceed predetermined limits.¹⁹

In some cases the criteria for interchangeability are simpler and the tolerances large. For example, the diameter of a sink in a plate has to be greater than the largest wheel to be put in it, but otherwise its size is fairly arbitrary. Another case is that, because pinions are often quite long, the position of the meshing wheel on its arbor is not subject to tight constraints. David points out that, because American wheels were mounted friction-tight on their arbors, they could be moved to mesh with a different part of a worn pinion. The Swiss riveted wheels onto pinions, and repairers could not take advantage of the unworn parts of a pivot.²⁰ However, in most cases the criteria for interchangeability are much more complex. Endshake, as we have seen, is also important in the case of a pivot, and this depends on arbor length, the distance between the plates, and the lengths of both pivots, all of which measurements have tolerances and which must lie within acceptable ranges. Obviously the planting positions of a complete train are dependent on the interaction of many tolerances, and the making of master plate gauges is critical to success.

Acceptable tolerances vary from one part to another and change in different circumstances. A watch pivot with a diameter of 0.1 mm, for example, may be only acceptable if it is within 0.01 mm of its correct size, an accuracy of about 1:10.²¹ In contrast, a 45 mm diameter seat for a dial plate in a pocket watch case would be unacceptable if it could vary by 1:10 and be 40.5 mm or 49.5 mm. Equally, it would be pointless to turn the seat within 0.01 mm, an accuracy of 1:4,500.

Such dimensional tolerances are not the only constraints; other factors also have to be controlled within acceptable limits. For example, very small changes in the quality of steel in—and in the hardening and tempering of—balance springs, will dramatically alter their behavior, even though the springs may apparently be identical in shape and size.

Clearly the ability to machine interchangeable parts depends on the ability to design and construct a suitable machine that will consistently work to the required accuracy. Of course, the smaller the part the more difficult it is, but the shape and critical dimen-

sions are very significant. So it is far easier to turn a round pin than to make a square peg. Similarly, it is much easier to make screws automatically than it is to cut levers for escapements.

Finally, tolerances vary with manufacturing objectives. The production of adjusted watches of chronometer standard requires very high accuracy in part production and involves considerable hand finishing. Ordinary, good-quality watches could, in contrast, be assembled from mass-produced parts with relatively little hand finishing, and constraints are even weaker for very ordinary products. David discusses the impact of the American Civil War and the manufacture of very cheap movements such as the Broadway, and he notes that “another advantage, which is of some importance from the point of view of the economy of manufacture, lies in the fact that a quality of parts can be used in these very ordinary movements that, because of defects . . . had until now been discarded.” Landes suggests that “truly interchangeable components” for jeweled watches were not produced until the 1930s and “many parts were altered and adjusted by hand.”²² But the same could not be said of cheaper “dollar” watches, where larger tolerances and lower accuracy enabled interchangeability to be achieved much earlier.

The adoption of a flexible definition of interchangeability, such as that suggested by Hoke, makes it easier to examine the subject, but it hides important distinctions.

One difficulty with such flexibility is deciding where to draw the line: When is a part interchangeable and when is it not? How much adjustment is permitted for a part to be still considered interchangeable, and how much adjustment indicates a unique part? Standardized English movements in the grey (manufactured in Lancashire) might be considered interchangeable because, after adjusting (e.g., finishing pivots, planting the train) they worked.²³ Perhaps more interesting are the movements made by Japy. Landes quotes an 1818 essay that says: “The pieces are all perfectly alike, the parts always match. . . . the maker who works up the rough movement loses no time in examining and contriving.” But if these movements, mass-produced in vast quantities, were interchangeable, why then were the developments at Waltham regarded with amazement and awe? I doubt if anyone would seriously suggest such English and French parts were in any real sense interchangeable.

Another problem is the assessment of causes. In Hoke’s very good analysis of private-sector industries, he says of wooden-clock makers, “they made their parts only as interchangeable as necessary,” correctly stressing the fact that cost was a fundamental factor, the concern being with what could be called *economic interchangeability*.²⁴ But was the machinery built to suit the clock design, or was the clock design dictated by

machinery limitations? David indicates that, in the jeweled watch industry, the machinery dictated, and, at that point in time, some parts simply couldn’t be made interchangeable, although they were adequate for a lower-quality product.

Third, as I have indicated above, subtle factors beyond just size can be critical, and interchangeability requires more than a part simply fitting; it must also behave identically to any other such part in that assembly. Which is why seemingly identical balances and balance springs are not interchangeable, and, as Hoke points out, wooden clock quality was restricted by the dimensional changes in parts caused by humidity.

The advantage of adopting a strict definition is that we can recognize and clearly delineate situations of *partial interchangeability*, where some parts are interchangeable and others are not.

The concept of partial interchangeability raises four very important questions:

1. Which parts are unique, noninterchangeable, and why?

The obvious reason for uniqueness is the inability to construct a machine that will operate within the necessary tolerances for the required product quality. But it may be for purely economic reasons; such a machine could be built, but its cost would be prohibitive compared with manual fitting.

2. Why is interchangeability necessary?

The driving force in government armories was the *postmanufacturing phase*, the exchange of parts on a battlefield. (But other gun users did not have this requirement, and guns rejected by the U.S. government were perfectly adequate for use by private citizens.) In contrast, wooden clocks had relatively few repair problems (they just wore out) and were rarely found in piles of bits discarded on battlefields; it was the *manufacturing phase* that was critical.

Watch manufacturing is especially interesting because both phases are very important. Making plates interchangeable is essential in the manufacturing phase so that a number of randomly selected components can be fitted (e.g., pillars, cocks, steady pins). Also, mass-produced wheels and pinions forming the train had to be placed with correct depthing and hence required very accurate positioning of their pivot holes. But interchangeable plates are also essential for after-sale repair, which could involve fitting of new wheels and pinions manufactured at a different time from the movement, yet the replacements had to form part of a correctly depthed train.

3. Which parts *need* to be interchangeable?

The two phases create different problems requiring different solutions and approaches to interchangeability.

In the case of watches, the important parts in the postmanufacturing phase are pivots, jewel holes, and balance springs (and mainsprings, but they were not a

major problem). These parts have the most exacting tolerances and are the most likely causes of failure in use. In contrast, making plates and bridges interchangeable was very important during the manufacturing phase, but such parts were rarely if ever broken or swapped and their postmanufacturing interchangeability is largely irrelevant.

4. To what extent were techniques developed to make parts interchangeable, and to what extent were techniques developed to overcome the *lack* of interchangeability?

By recognizing that some parts were unique and examining their production and use, we can usefully classify and compare different processes. For example, David's explanation of the Record and jewel setting makes it clear that some tools and many gauges were explicitly designed with unique parts in mind.

David's concept of interchangeability matches the strict definition given above. One example is that David repeatedly comments on the advantage of a small number of standard calibers or models, not only because doing so enabled completely separate case manufacture but also because it enabled the available capital to be focused on fewer (and hence better and more complete) machines. He notes that an attempt by Elgin to produce a nonstandard caliber failed because of the difficulty in getting cases made for it.

Indeed, David implicitly pays particular attention to my fourth question relating to partial interchangeability—to what extent were techniques developed to make parts interchangeable, and to what extent were techniques developed to overcome the *lack* of interchangeability?

Conclusions

This case study clearly demonstrates the advantages, and indeed the necessity, of using a strict definition of interchangeability. First, there is no doubt that watch manufacturers took such a view, recognizing that some parts were not interchangeable and taking complex and sophisticated measures to compensate for this lack of interchangeability. Further, by taking a rigorous approach we are forced to examine interchangeability very carefully, identifying situations of partial interchangeability, and investigating the processes developed for noninterchangeability as well as for interchangeability. Finally, we have seen that the time when interchangeability is needed—during manufacture and/or after sale—can be a significant factor.

In contrast, a loose definition that allows “interchangeable” parts to be adjusted and fitted can result in such important distinctions being missed and could lead to a less than adequate understanding of manufacturing processes.

Notes and References

¹ Jacques David, *Rapport a la Societe Intercantonale des Industries du Jura sur la fabrication de l'horlogerie aux*

Etats-Unis (Saint-Imier: Compagnie des Montres Longines Francillon, 1992). The translation, *American and Swiss Watchmaking in 1876: Reports to the Intercantonal Committee of Jura Industries on the Manufacture of watches in the United States*, is available from www.watkinsr.id.au or by email to books@watkinsr.id.au.

² For example, Charles Moore, *Timing a Century* (MA: Harvard University Press, 1945) and David Landes, *Revolution in Time* (MA: Harvard University Press, 1983 and 2000). Both quote from a speech reprinted in *La Nationale Suisse*, November 17, 1876. Also, Favre-Perret wrote *Rapport presente au haut conseil federal sur l'industrie de l'horlogerie, Exposition de Philadelphie 1876* (Winterthur, 1877). I do not know if this has been printed.

³ The following is derived from the biography (by Jacqueline Henry Bédât) and history of the manuscript (by Jean-Marc Barrelet) prefacing the 1992 Longines facsimile edition, and from André Francillon *Histoire de la fabrique des Longines* (Saint-Imier: Compagnie des Montres Longines Francillon, 1947).

⁴ It is sometimes forgotten that the Swiss watchmaking industry was a massive part of the country's economy and, indeed, almost the sole source of income for much of the Jura and Geneva. Consequently, a crisis in the watchmaking industry threatened the entire population of Switzerland. In contrast, though watchmaking was important in the United States and England, it was a minor part of the economies of those countries, and utterly dwarfed by other industries.

⁵ At least two copies have survived. André Francillon's *Histoire de la fabrique des Longines* reproduces the last page of a copy of the first report signed by David and a drawing of a screw-cutting lathe. Both the pagination and drawing details are different from the facsimile published by Longines, but the handwriting is similar and David may have penned both. I presume this other copy still exists.

⁶ Most notably, Charles Moore, *Timing a Century* and Michael Harrold, *American Watchmaking* (Columbia, PA: NAWCC, 1984).

⁷ The theory of epicycloid gearing had been known since a treatise by de La Hire in 1694, but the difficulty of shaping small watch wheels meant that correct teeth forms were almost never used; epicycloidal addenda were approximated by guesswork based on bay leaves and thumbs or replaced by circular addenda; see, for example, Charles Higginbotham, *Precision Time Measures* (Chicago: Hazlitt and Walker, 1913), Louis & Samuel Levin, *Practical Benchwork for Horologists* (Los Angeles: Horology, 1938), and George Daniels, *Watchmaking* (London: Sotheby, 1981). Tarasov in *Technology of Watch Production* (Jerusalem: Israel Program for Scientific Translations, 1964) admits that the “reason for the replacement of the epicycloids by circular arcs in gear-wheel teeth lies in the difficulty of producing milling cutters of epicycloidal contour.” The description by David is the only “practical” method for making epicycloidal cutters that I have read.

⁸ Donald Hoke, *Ingenious Yankees—The Rise of the American System of Manufactures in the Private Sector* (New York: Columbia University Press, 1990). Most but not all of the chapter on watchmaking is reproduced in Donald Hoke, *The Time Museum Historical Catalogue of*

American Pocket Watches (Illinois: The Time Museum, 1991).

⁹ David Landes, *Revolution in Time* (second edition only, 2000).

¹⁰ The reports do not describe every process in detail. David concentrates on those not used by the Swiss, and if a method is common knowledge he says it is “not interesting” and does not describe it. For example, he ignores hardening and tempering, except to notice that only one person does it, a division of labor that he feels is noteworthy. Likewise, he very briefly summarizes case and enamel dial making, but he gives a precise explanation of how dial plates were made and dial-feet attached. Consequently David indirectly gives us an interesting comparison between Swiss and American methods.

In addition, David did not have the opportunity to see and examine every aspect of watchmaking in the factories, and in a few places he notes this reason for being unable to provide details.

¹¹ Donald Hoke, *Ingenious Yankees*.

¹² My emphasis.

¹³ It is interesting to compare this master plate tool with the sophisticated plate lathe developed and patented by Ingold; described in R. F. and R. W. Carrington, “Pierre Frederic Ingold and the British Watch and Clockmaking Company,” *Antiquarian Horology*, Vol. 10 (Spring 1978), pp. 698-714. This plate lathe appears to be the only major contribution by Ingold to machine manufacture (other than his fraise), but all it achieved was more regularity in handwork by a not very convenient method. As the authors note, there is no convincing evidence that Ingold had any influence on American watchmaking at all, despite the suggestion that his son-in-law worked for Dennison. However, there are vague similarities between Ingold’s face plate and the master plate tool, in that both use an adjustable mounting to center any part of a plate, with the required positions selected by indexing marks. It would be unwise to conclude that Ingold influenced the design of the master plate tool, but it deserves further investigation.

¹⁴ This tool is described in several books, so I omitted David’s illustration and description. See, for example, Abbott, *Abbott’s American Watchmaker and Jeweler* (Chicago: Hazlitt, 1894 and other editions), Levin, *Practical Benchwork for Horologists* (Los Angeles: Louis Levin & Son, 1938 and later editions) or Britten, *Watch and Clock Makers’ Handbook*.

¹⁵ This machine smoothed and polished cylindrical pieces with a thinned iron file given a rectilinear motion with very fast forward and back movements. The only pictures of wigwags that I have found are in F. J. Britten, *Watch and Clockmakers’ Handbook, Dictionary and Guide* (there is no description), and H. L. Belmont, *L’Echappement a Cylindre 1720-1950* (Besancon: Technimedia Editions, 1984) which has a photograph of a hand-operated wigwag from Switzerland.

¹⁶ Elsewhere David points out that considerable care was taken to ensure that the overall length of arbors was constant. The variations in pivot length result from variations in their shoulders.

¹⁷ This tool is also described in N. B. Sherwood, *Watch and Chronometer Jeweling* (1892, George Hazlitt, reprinted

1988, Arlington Book Co.) where it is called an endshake tool. Sherwood’s explanation is unfortunately obscure and inadequate, partly because it is described in the context of repair. David’s description shows that its primary use was for manufacture, the repetitive processing of batches of watches after the tool had been set up with a standard arbor.

¹⁸ Donald Hoke, *Ingenious Yankees*.

¹⁹ In fact, mass-produced parts cannot be guaranteed to lie within such theoretical limits, and control of manufacturing may have to be based on statistical analysis of batches; see S. V. Tarasov, *Technology of Watch Production* (Jerusalem: Israel Program for Scientific Translations, 1964).

²⁰ I have read, in a repair book whose name I have forgotten, the suggestion that a wheel could be dished to achieve this; a cheap but unpleasant solution, riddled with problems.

²¹ Waltham had switched to the metric system for most measurements in 1868. 1 mm is approximately 0.039 inch, 0.1 mm = 0.0039 inch, and 0.01 mm = 0.0004 inch.

²² David Landes, *Revolution in Time*, both editions. He also cites a “demonstration” of interchangeability by Waltham at the 1878 Paris Exhibition which consisted simply of swapping cases!

²³ Probably the best explanation of English finishing procedures is given by David Glasgow in *Watch and Clock Making* (London: Cassell & Co. 1885).

²⁴ Donald Hoke, *Ingenious Yankees*.

About the Author

Richard Watkins lives about as far as you can get from the centers of horology (in Tasmania, the little bit under Australia). He spends a lot of time using computers and reading books about watches. He dislikes clocks. He has produced two other translations: Moritz Grossmann’s *Prize Essay on the Construction of a Simple But Mechanically Perfect Watch* and Jérôme Lalande’s *Diary of a trip to England 1763*. Both, which were undertaken in futile attempts to avoid mowing the lawn, are available from www.watkinsr.id.au or by e-mail at books@watkinsr.id.au.

American and Swiss Watchmaking in 1876, reports to the Intercantonal Committee of Jura Industries on the manufacture of watches in the United States, translated by Richard Watkins (published by Richard Watkins: Tasmania, Australia, November 2003). This book is available from Richard Watkins, 41 Gryces Rd., Kingston, Tasmania 7050, Australia. E-mail: books@watkinsr.id.au or website: www.watkinsr.id.au

This softcover book contains 82 pages with 42 illustrations. The price is \$31.00 AUD or approx. \$24.50 U.S., including airmail postage and packing. Visa and MasterCard payment are accepted.

Make a detailed evaluation of a course book or set of materials that is used in your own working context. You should consider both the syllabus followed and the methodology employed. Question 7 rated the highest, which was about the recycling of language learnt. I propose that the emphasis on lexis stated by the authors (Cunningham and Moore, 2004a:12) is helpful for the students. Common "prefabricated chunks" (Cunningham and Moore, 2004a:12) blur the boundary between vocabulary and grammar and aid students with problematic areas that are traditionally considered to. With an emphasis on design and performance of precision machinery for manufacturing machine tool elements and structure, sources of error, precision machining processes and process models sensors for. The book starts with a historical introduction to the process of manufacturing in general, and machining in particular, and ends with a chapter devoted to environmental issues involved with machining. The references section, containing 560 published articles dealing with every aspect of precision machining, is particularly useful.