THE FALL-HAMMER, CHRONOSCOPE AND CHRONOGRAPH.

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Criticisms on the Wundt fall-hammer.—Defects in the Zimmermann model and their correction.—Reliability of the break spark in chronograph records.—Latency of magnetic markers shown by spark method.—Timing fall-hammer from break to break of current.—Timing from break of current through supporting magnet.—Effect of occasional reversal of current on Hipp chronoscope.—Spark method of recording movements of chronoscope armature.—Effects of unreversed current on chronoscope.—Advisability of never reversing.—Lower winding for Magnets.

THE following observations on the testing¹ and manipulation of the Wundt fall-hammer, Hipp chronoscope and certain chronograph accessories are offered on account of their interest in connexion with the operation of other pieces of apparatus of analogous structure, as well as because of their importance for the accurate use of the instruments mentioned.

The large model fall-hammer has been orally condemned by various American psychologists as being difficult of adjustment and inaccurate in operation. In print, Cattell², while not certifying to the unreliability of this particular model, states that he believes the fall-apparatus designed by himself to be a more accurate instrument. "Ich bezweifle zwar nicht, das der von Külpe und Kirschmann verschriebene Fallhammer recht wohl zur Regulierung des Chronoskopes dienen kann, aber ich glaube, ein Fallschirm ist besser." Edgell and Symes, in their

¹ The tests reported herein were made with the assistance of George R. Wells.

² J. McK. Cattell, "Chronoscope und Chronograph," 1894, *Philos. Studien*, ix. 307—310.

first statement¹ concerning the large fall-hammer, declare it to have a negligible variation in its fall-times, and imply that it is a very satisfactory instrument; in their second note², a few months later, they virtually recant this commendation, saying that the instrument did not wear well, and that the methods by which they had timed it were quite unreliable.

The most interesting data on the operation of the fall-hammer are those supplied by Külpe and Kirschmann in their original account of the instrument³. They find for the average fall-times, ranging from 616σ to $56\cdot6\sigma$, mean variations ranging from 2.8 to 0.6, respectively. This is remarkable, inasmuch as the fall-hammer is virtually a pendulum, and ought to be operable with practically no mean variation, unless there are grave defects in its construction.

In using the large model fall-hammer made by Zimmermann (No. 1300, price list No. 20), we have found no serious difficulty in obtaining fall-times practically without variation, when measured from make to break, although careful handling of the instrument was necessitated by structural defects which will be detailed shortly. When we attempted to time the fall from break to make, using magnetic markers, we found a large variation, and on this account have made a careful study of the instrument's action, and have made some changes which seem decidedly good.

In the following descriptions we shall refer by letter to the cuts of the fall-hammer and contacts given in Wundt's *Physiologische Psychologie*, 5th ed., Vol. III., Figures 358, 359 and 360, pages 397, 398 and 399. These cuts are identical with Figures 1, 2 and 3, in the article by Külpe and Kirschmann.

There are some differences between the Krille instrument and the one made by Zimmermann, but these will be specifically mentioned, in so far as they are important for the present discussion.

The magnet (*E*, fig. 358) is held in position on the transverse rod by a simple sleeve and set screw. When adjusted for short or medium falls, the magnet is necessarily placed at a considerable angle from the vertical, and we found it impossible, under these conditions, to prevent it from gradually swinging toward the vertical, thus appreciably changing the total fall-time if frequent readjustments were not made. The set

¹ B. Edgell and W. L. Symes, *This Journal*, 1906, II. 58—88.

² *Ibid.* 281—283.

³ O. Külpe u. A. Kirschmann, "Ein neuer Apparat zur Controle zeitmessender Instrumente," *Philos. Stud.* 1893, VIII. 145—172.

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screw could not be tightened enough to prevent the rotation of the sleeve on the transverse rod under the influence of the heavy jar of the fall. We have had the simple sleeve replaced by a split sleeve, with lugs projecting above the transverse rod, and a heavy clamping screw through the lugs. This sleeve may now be clamped so tightly on the rod that it is absolutely immovable.

In timing from break to make, by the spark method, we found a clear break-spark, a fair make-spark, and then a succession of sparks, trailing out over an interval which was often more than 100σ . This after-sparking we soon found to be due to the bouncing of the floating lever of the lower compound contact-key (the lever bearing the post *sq* and contact plate *p*, fig. 360), caused by the jar of the fall. Thus are explained at once the variations in the times recorded by magnetic marker and by chronoscope: the irregular and rapid interruptions of the current prevent the uniform re-establishment of the magnetic field.

The spring *r'* (of a different type in our instrument) could not be given sufficient stiffness to stop the bouncing. The floating lever was about five times as heavy as is necessary, and this exaggerated the trouble. There was even a heavy binding post on the lever. It was necessary to reduce the weight of the lever, and it was desirable to add a spring which could be adjusted to give adequate tension.

We had the floating lever reduced in width, the binding post removed, and a light flexible conductor run from the lever to a post on the base (*b*). We also had another binding post mounted on the base, and a light flexible conductor run to the lever (*l*). In the original form of the machine, the leading wires were necessarily connected directly to the levers, so that the slightest disarrangement of the wires changed the action, introducing serious errors in the readings. It was absolutely necessary to have this defect remedied—to have the additional binding posts on the base.

We have not yet had the spring added. We found that a strong rubber band could be satisfactorily used, and have so far used one on the lower compound key. Although we have had the upper compound key modified in the same way as the lower, we have not had to increase the spring tension on it, as the bouncing of this lever makes no difference, whether we are using the hammer from make to break or break to make. If it is ever necessary to use the hammer from make to make, an additional spring would be needed on the upper lever also. The simple break contacts of the instrument (fig. 359) have also been

improved by a single binding post on the base, with light flexible conductor to the lever (*l*).

The figures 1 to 6 (pages 46, 47), are tracings taken with the 250 *d. v.* fork on the modified Schumann chronograph. These records are to be read from left to right, *B* indicating beginning and *E* ending. The upper lines in figures 1 and 5 are the tracing of one stylus of the *Doppel-markiermagnet* made by Zimmermann (No. 1802, List 20). The upper tracings in figures 2 and 4 are made by the *Federsignal nach Pfeil modif* (Zimmermann, No. 1830, List 20). These are all records from break to make, taken with the fall-hammer. The sparks on the accompanying fork tracings are also break to make, the circuit through the spark-coil primary having been broken and made simultaneously with the break and make of the marker current. The vertical lines were drawn by disconnecting the gearing of the chronograph, clamping the drum in position, and drawing the fork along the drum in the normal way by rotating the carriage-screw. The points of the fork and the magnetic marker in each case had been adjusted on a similar line before the record was taken. The lines marked (1) are drawn through the sparks marking the actual break or make of the current. The lines marked (2) are drawn near the points of inflection of the marker tracing, but no attempt was made to get these placed accurately. The upper tracing in figure 3 is from one of the magnetic markers supplied with the Schumann chronograph (Spindler and Hoyer, No. 17, List 21; see F. Schumann, *Philos. Stud.* ix. pp. 260—262). In this record, which reads from make to break, the current was made and broken through the marker by an automatic key attached to the chronograph. Many other records were taken from all three markers, both with fall-hammer and with the drum-key, using varied current strength. The records given are strictly representative.

The effect of the improvement of the contact-keys of the fall-hammer is marked. Compare for example the make-latency of the marker in figure 1 with the same latency in figure 5. Although in the latter case the current is weaker and the spring stronger, the latency is markedly reduced. The effect on the Pfeil marker is of the same order, but shows rather as increased legibility.

Before the floating lever was reduced in weight, tests were made on the chronoscope, with constant adjustment of fall-hammer, chronoscope and current, but in one case without, and one case with, the rubber band. The following two series, taken in succession, are typical; the figures representing thousandths of seconds (σ):

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<i>A</i> (Rubber band on floating lever of fall-hammer)	<i>B</i> (Without rubber band)
305	358
306	342
306	357
305	361
307	350
306	344
307	361
306	358
307	356
307	343

Suppose, now, an approximately correct timing of the fall-hammer had been obtained (as might easily have been done by taking the record from make to break), and the hammer had been used to control the chronoscope from break to make, without regard to the effect of the bounce; an error of over 40σ would have been introduced.

We have adopted the spark-chronoscope as the only adequate means of testing the fall-hammer or other control instrument, where no direct tuning fork record is available such as is possible where an arc is attached to the fall-hammer. We use preferably the break-spark only, as that is perfectly reliable, whereas the make-spark, although sufficiently reliable for most practical purposes, does show slight variation at times, and in order to get a good make-spark it is necessary to use a current which gives a break-spark so heavy as to burn the carbon from a considerable area around the actual perforation of the paper.

That the break-spark is reliable, even with low current, we have abundant evidence. The record in figure 6 is one instance. The current was broken by our automatic key attachment to the chronograph, and the vertical line in the record shows the position of the tuning-fork point when the arm just touched the lever and the contact was still unbroken. It can readily be seen that the delay in the spark is negligible.

Similar results were obtained with currents ranging from 1.9 amperes to 10 amperes, with voltage not exceeding 10 volts with current broken.

The sparks following the break are due to the remake of the current and the vibration of the key. This could be easily obviated, but was of no importance in this particular record. It will be noticed that occasionally there are two break-spark perforations. Nevertheless, the first of these is always correctly placed and the second can therefore be neglected. This doubling of the perforation is a function of the length of the spark discharge, which, under our working conditions, was sometimes 6σ or 8σ .

Of course, apparatus may be so arranged that considerable delay in the spark occurs. It is necessary to make tests under the exact working conditions, as we have done, to certify that these conditions are appropriate. The spark method cannot be successfully applied by an experimenter who has not considerable practical knowledge of the action of electrical currents.

On the question of the availability of magnetic markers when the spark method cannot be used, the records here presented are illuminative. In obtaining record 1 the strongest tension of the spring was employed, with relatively high current (.57 amp.) and minimal movement of the armature; in obtaining record 5 the spring was cut, shortening it so as to obtain greater tension. By no adjustment of spring could we obtain a more satisfactory tracing than in record 5.

Records 2 and 4 were obtained from the Pfeil marker, with 1.0 ampere of current. The magnet is lower wound than that of the double marker. This instrument is very sensitive, but no great amplitude of movement can be obtained without sacrificing accuracy; hence, at high speeds of the drum the points of change in the line are almost undiscoverable.

The marker on the Pfeil principle supplied on the Schumann chronograph (figure 3) is not as reliable as the small Pfeil marker, principally because the magnet is wound too high. We do not use the Schumann markers at all, but have removed them from the chronograph and substituted the Pfeil marker. When we consider the use which in the past has been made of unsuitable markers in all sorts of time work, we must have grave doubts of the reliability of much of the resulting data.

One particularly bad feature of the Zimmermann fall-hammer, which is inexcusable, is the absence of lock nuts from the adjusting screws. The Krille instrument had lock nuts on the contact screws, but not on the screws which adjust the springs. All these screws must have lock nuts, as a slight change in the contact screws changes the time, and a change in the spring screw of the upper contact key may also produce a time change. The lock nuts are replaced in the Zimmermann instrument by split ends on the levers, but these are not satisfactory substitutes.

In timing the fall-hammer from break to break, the primary current is arranged through the upper contact and the coils of a Cattell relay, the two coils of the relay being connected in parallel to reduce the resistance and reluctance. When the upper contact is broken, the relay armature moves over, and completes the primary circuit through the lower contact, so that it may be rebroken by the hammer. The

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action of the relay may introduce some sparks between the initial and terminal break-sparks, but these do not cause any confusion. In theory, there should be more delay of the spark when the first circuit is interrupted than when the second is interrupted, but practically there is no difference; there is no appreciable delay in either case.

In attempting to time the fall-hammer from the break of the current through the supporting magnet to the break of a second current through one of the contact-keys, large variations were found. In one series, for example, the recorded times ranged from 171σ to 178σ , inclusive, and this is typical of series in which the counterpoise was set near the pivot. With the counterpoise set far out, so that the downward pull at the magnet is small, the variation may be as much as 20σ . There is rather obvious bearing of these variations on the question of accuracy in certain models of the pendulum chronoscope, in certain types of fall-apparatus, and such reaction-times as those obtained by Froeberg¹, where the time was measured from the break of the current through the magnet holding a ball, the computed time of fall of the ball being subsequently subtracted from the measured time.

In regard to the Hipp chronoscope itself, the remarkable work of Symes and Edgell has confirmed and added to the results obtained by Külpe and Kirschmann, Müller and Schumann, Kraepelin, and Ach, and conclusively proved that the Hipp is not influenced by the length of time during which the current runs through the magnets for timing of extents as small as the shortest simple reaction, or longer. So far nearly all experimenters have assumed the necessity of reversing the current, frequently, if not after each reaction, through the chronoscope magnets; and no one has made a real test of the advantages or disadvantages of not reversing at all. Edgell and Symes state that "occasional omission to reverse, gives rise to no appreciable irregularity in a series of chronoscope readings of equal periods" (p. 76).

This statement is not in agreement with my own observations. I have found it much better to keep the current flowing constantly in the same direction through the magnets, and have found uniformly that if in a series in which the current is reversed after each record, reversal is omitted once, the time following the non-reversal is longer than the other times. The next reversal, however, is followed by a reading of the same length as the normal reading following reversal. This is for readings from make to break. If the chronoscope is set up for break to make, it makes absolutely no difference how regularly or irregularly

¹ Froeberg, Sven, *Archives of Psychology* (Columbia University), No. 8.

the current is reversed. The effect of the reversals on the chronoscope running from make to break is clearly shown by the results of the series taken in a way which will now be described. The magnet having been depolarized, the fall-hammer set for 106σ , the hammer was dropped twice and the readings not recorded. Readings were then taken from the succeeding falls, the direction of the current being (1) reversed, (2) reversed, (3) reversed, (4) not reversed, (5) reversed, and so on, the current therefore being reversed before each fall except the 4th, 8th, 16th, and so on. Fifty-two readings were taken, 13 for each of the four cases. The averages and mean variations for the four cases are here given. (4) is the average of the readings before which the current was not reversed, and (1), (2) and (3), respectively, are the averages for the first, second and third readings after the non-reversal.

(1)	Av. 111.7	m.v. 1.0
(2)	„ 111.7	„ 1.4
(3)	„ 111.9	„ 1.0
(4)	„ 118.2	„ 1.2

The variation is a little high in these series, owing to the particular setting of the fall-hammer. The variation arises from the errors in the reading (an error of 1σ is always possible in this particular chronoscope, although not highly probable); the actual error in the chronoscope; and the adaptation error due to the fact that the virtual chronoscope time is (in the first three cases) between 111σ and 112σ , a time which the chronoscope is of course incapable of recording. In most cases, adjustment of the chronoscope springs or current which brings the average recorded fall-time as near as possible to an integral value, also reduces the mean variation to a minimum value.

The obvious interpretation of the results, of which those given above are typical, is that a slight magnetization is left by the current, and that the next current, if in the opposite direction, has to overcome this remanent magnetization before inducing the opposite polarity. If successive currents are in the same direction, the remanent magnetization is in the direction of the second polarity, which is therefore established a little quicker than in the case where the polarity is opposed. In any case, the remanent magnetization at the end of a current period of 100σ is independent of the conditions at the beginning of that period.

We next took records of the movement of the chronoscope armature, and these gave complete confirmation of our interpretation. The direct writing attachment used by Edgell and Symes is of course the most

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reliable method of recording the armature movements, but for convenience we adopted a different method. A light arm was attached to the armature, with platinum contacts touching contact screws above and below, so that when the armature was in either extreme position, contact was made. The current was made to flow through these contacts and the primary induction coil. The drop of the hammer (the chronoscope being connected from make to break) caused the armature attachment to move from the upper contact to the lower, and then return. Since the make-spark in no case penetrated the paper on the chronograph drum, the movement produced only two sparks, the first when the armature began its upward movement, and the second when it began its return movement. These spark records were taken in our usual fashion with the 250 d.v. fork, and with the record of the Pfeil marker alongside, indicating the points at which the hammer made and broke the chronoscope current. The Pfeil marker was slightly variable in its action, and not all the records obtained from it are legible, but we obtained enough records to make it perfectly clear that the variation in the latent period of the chronoscope at the break of the current, running from make to break, is independent of the preceding reversals of the current, whereas the delay at the make of the current when the flow was in the same direction as in the preceding record was shorter than when the current was reversed between records. The shortening of the latent period in this case corresponded with the lengthening of the chronoscope record.

We had earlier supposed that there might be a progressive change in the chronoscope error, when the current is never reversed, due to the increase in the amount of the remanent magnetization. Careful tests have shown conclusively that nothing of the sort takes place. Starting with the magnets demagnetized as far as possible, and neglecting the first record, we have found that the succeeding records show absolutely no progressive change.

The following are the averages of ten records, chronoscope make to break, springs 0 and 10, current .08 ampere. The current was in the same direction throughout, and was allowed to run continuously for 19 seconds between the first and second, second and third, and third and fourth series. The magnets were practically demagnetized before the first series, as was indicated by specific tests.

Series	1	2	3	4
Average	192.6	192.1	192.3	191.8
m.v.	1.0	0.8	0.5	1.4

Another set was taken with conditions at start as in the preceding, but the current was in this set 0.145 ampere. Ten reaction falls were timed, and then the current was allowed to flow for two minutes, being rapidly interrupted by the vibrator of an induction coil. Then a second series of ten was taken, the current being in one direction throughout. The averages for these two series were 198.9σ and 198.2σ , respectively, with mean variations of 0.3 and 0.6 respectively. A number of other series was taken with different current strength and time relation, but in no case was any progressive error discoverable. There can be no doubt that progressive change in the error from day to day, when it occurs, is due to the progressive weakening of the chronoscope springs.

The reversal of the current through the chronoscope magnets is clearly useless, and is apt to introduce errors of appreciable amount, since the experimenter is certain to forget frequently to reverse the commutators. In the case of more sensitive magnetic apparatus, as for instance the Pfeil marker, reversal of the current, even when regularly done, introduces serious errors, the latent periods being different for the two directions of current. A similar effect is found with the electrically driven fork; seldom, if ever, can the reversals of the current be so made that the intensity of the sound is the same for the two directions.

The only suggestion for the improvement of the Hipp chronoscope is that the magnets should be wound with fewer turns of coarser wire, thus reducing the reluctance and shortening the latent periods.