

CONSTRUCTION OF A CIRCULAR WARBURG APPARATUS FOR 32 MANOMETERS

by

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GENERAL CONSIDERATIONS

The scope of new investigations made it desirable to use a Warburg apparatus for 32 manometers instead of 14, as usual in our laboratory. A circular thermostat was chosen for this apparatus. This made it possible to move the manometers around the thermostat, simplifying inserting and reading of the manometers by the manipulator. Moreover the location in the room is subject to less restrictions as the apparatus need not be accessible on 3 sides as is the case with a rectangular water bath and two rows of manometers.

The construction had to meet the following requirements:

1. the parts had to be machined from normal sizes of steel, brass and aluminium profiles and sheets;
2. castings could not be used, as these are generally too expensive to use in an apparatus which is not built in series;
3. the parts had to be machined in a normal laboratory workshop with a lathe of $6\frac{1}{4}$ " height of centres, $3\frac{3}{4}$ " between slide and centre, and 10" height of centres with gap piece removed.

Larger circular plates (Fig. 3, (17)), which had to be shaped in a factory by auto-genous cutting, should not require further machining of the plane sides or the inner circle. (The manner of machining the circumference of the manometer plate (Fig. 2, (2) is described later on.);

4. the manometer holders should correspond with those already present in the laboratory to ensure interchangeability. As to this requirement it is stressed that in case of different types of manometer holders certain self-evident dimensions in the drawing have to be changed.

The Warburg flasks are pivotally shaken, the axis is placed in the centre of the scale behind the manometer limbs. The menisci are hardly agitated by this arrangement and the rotatory movements of the manometer limbs are minimal. The rotation of the knurled knob for the manometer adjustment did not interfere at all with the adjustment of the manometers during shaking. Should manometers be designed especially for this kind of apparatus, it would be advisable to locate the adjusting knob as close as possible to the axis of rotation.

CONSTRUCTION*

A general view of the apparatus is given in Fig. 1 and Fig. 2. The apparatus consists of a square base of I-steel on 4 legs of 2" steel piping. On this base a 5" hollow column is mounted as a support for the thermostat. Around this column 2 ball bearings are mounted, one for a circular plate ("manometer plate") with greater diameter than the

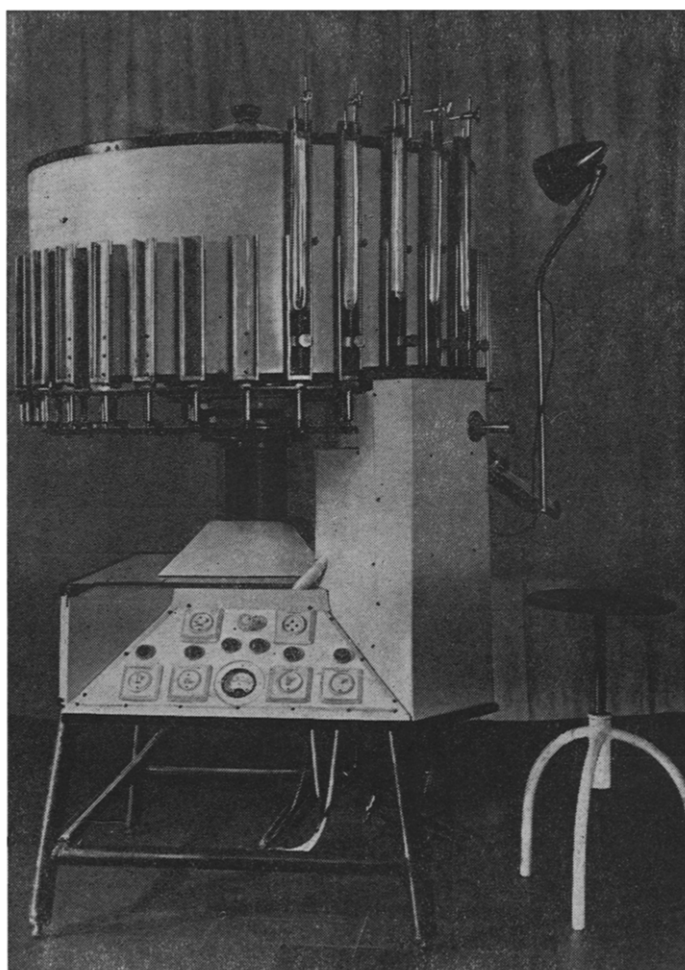


Fig. 1. Photograph of the complete apparatus

thermostat, carrying the manometers, and one for a plate providing the shaking mechanism for the manometers ("shaking plate"). Both plates together can be moved around the thermostat by means of a motor-driven pulley, controlled by a foot lever, in order to move the next manometer in front of the observer. The observer has both

* The numbers between brackets refer to the list of parts of the drawing in question.

The approximate (non-essential) dimensions can be measured in the drawings in all cases where the exact dimensions have not been stated. Interrupted lines with underlined dimensions are not drawn to scale.

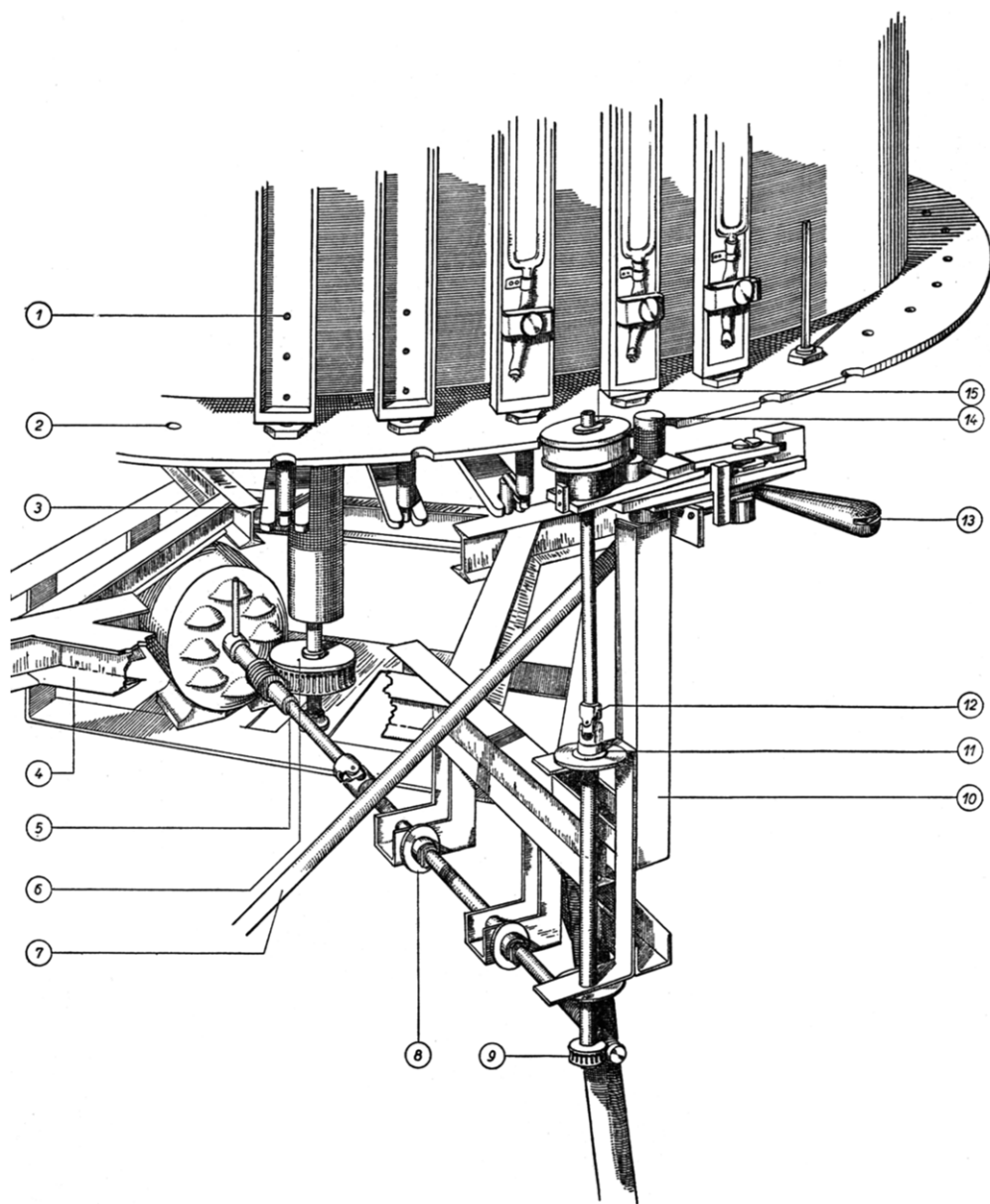


Fig. 2. Schematic view of the driving mechanism and the base

1. manometer supports, some with manometers; 2. manometer plate; 3. shaking plate; 4. upper part of base; support for column and column are not drawn; 5. worm gear for stirrer shaft; 6. stirrer shaft and guiding tube; 7. oblique reinforcement; lower end attached to the base (see Fig. 3, II, A); 8. ball bearings; 9. worm gear for driving shaft; 10. support for driving shaft; 11. ball bearing; 12. universal joint; 13. disengaging lever on lower plate of driving mechanism; 14. locking device of driving mechanism; 15. pulley of driving mechanism.

hands free for adjusting the manometer and taking down the results: for that purpose a small desk is attached to the base. The driving mechanism can also be completely disengaged; in that case the manometer plate can be turned by hand in all directions.

In a direct line with the hollow column a tube is erected in the thermostat, on which are attached the heater and the thermostat controls for either 27° C or 37° C. The column and tube serve also for guiding the stirrer shaft, tubes for cooling and emptying the thermostat, and the electric wiring of the thermostat. A control panel for the motors and the thermostat is built in the base.

Though it might have been possible to use a single motor for stirring, shaking and moving the manometer plate, we used a separate motor for the shaking mechanism; in the other case the inevitable clutches and the independent speed regulation would make the construction unnecessarily complicated and diminish the operational safety.

DETAILS OF THE CONSTRUCTION

A. Base (Fig. 3, I, II)

To obtain the necessary rigidity with regard to the non-negligible moment of inertia occurring when coupling and disengaging the manometer plate, the frame had to have a fairly sturdy construction. The upper part (3) is constructed of I-steel 100 × 50 mm, welded together all over. The 4 legs with triangular reinforcements (6) are welded to the frame. The legs are provided with $\frac{3}{4}$ " levelling bolts (7). The foot lever for the moving mechanism can be attached to one of the transverse reinforcements (8) of $1\frac{1}{2}$ " piping. The support (I) for the column (III) is fastened to the frame with 20 bolts $\frac{1}{4}$ " × 25 mm. The different parts of the support are welded electrically to prevent warping. The thread (M $1\frac{1}{2}$) in the support, into which the column (13) fits, is cut after welding the whole together.

At one of the ends of the frame U-steel is welded, to which the ball bearings of the driving mechanism are bolted (2, 5, see also Fig. 2, (10)). An extra oblique reinforcement from the upper part of the disengaging gear (Fig. 5, (1)) to one of the legs (near (A)) proved to be necessary.

With regard to the different sizes of electromotors it may suffice to indicate that a $\frac{1}{6}$ HP, 1400 r.p.m. motor for the stirring and driving mechanism is suspended on rubber on straps below the frame (4, 9); the motor is coupled to the driving shaft by means of a universal joint.

The column (Fig. 3, III, (13)) on which the thermostat rests is made of 5" steel piping, with M $1\frac{1}{2}$ thread over the whole length; the top and bottom surfaces are turned off levelly. On the upper flange a platform of plates (15, 16, 17) is erected. In the calculation of the necessary strength a water load of 50 cm height and the empty weight of the thermostat are taken into account, and also an accidental load of 70 kg on the outer wall of the thermostat. The dimensions of the platform plates (15, 16) are amply sufficient; for practical reasons it was desirable to exceed the calculated thickness, with regard to the shearing forces on the treated part of the column in unilateral load.

The inner and outer diameter of plate (17) requires no further machining after autogenous cutting. The plates (15) and (16) are provisionally bolted together and in both M $1\frac{1}{2}$ thread, fitting on the column, is cut. Plate (17) is placed on the upper edge of the column, plates (15) and (16) are screwed on the column close to (17); now the holes in (15, 16) can be copied on (17) and the whole is bolted together with $\frac{3}{8}$ " counter-

sunk bolts (see III, top view). The lower plate (15) is next welded to the column at four points. In this way the platform can be attached rigidly and at right angles to the column with limited means.

The tube (12) with ball bearings (11) on the upper and lower ends serves for guiding the stirring shaft and is bolted to the column at the appropriate distance (14). The lower end projects just above the worm gear on the driving shaft (Fig. 2, (6)).

B. *Thermostat* (Fig. 3, IV, V)

The use of 32 Warburg flasks in a not too compact mounting made a diameter of 975 mm of the thermostat desirable. The thermostat is made of 1 mm half hard copper sheeting, reinforced on the outside with two $\frac{3}{8}$ " $\times$ 1" steel rings (29). On the exterior of these rings a zinc outer jacket is attached, projecting so far that it almost reaches the manometer plate. In the part of the zinc jacket between the platform and the manometer plate there is an opening with cover for inspecting and oiling the motor and worm gear of the shaking mechanism (see Fig. 6). The space between jacket and thermostat wall is packed with asbestos. Between the platform and the thermostat bottom 3 mm of asbestos sheeting is placed.

To obtain turbulent flow when stirring, resulting in the most efficient thermostat control, four perforated shields (25, 30) and one half spiral shield (21, 36) are provided. The four nickelplated brass stirrers (20, 27, 28, 31, 35, 38, 39) are bent in a way to direct the flow inwards, outwards, upwards and downwards respectively. At 37° C and 15 r.p.m. of the stirrer the differences in temperature between various points of the bath are less than 0.01° C.

The 800 Watt tubular heating element (23, 34) with a length of about 2 m is bent to form a circle of diameter 55 cm; the ends are bent inwards and upwards, projecting along the centre tube (22, 37), where the wiring is attached. A copper tube for cooling, of similar shape (24, 33), with joints to tubes going down the centre tube and down the column, and a siphon for emptying the thermostat are provided. To prevent electrolytic corrosion of the brazing seams the whole thermostat is painted twice over with bituminous anticorrosive paint.

C. *Manometer plate and shaking plate* (Fig. 4, 6)

Fig. 4 shows a section through the left half of the bearings. Symmetrical parts in the bearings are not numbered separately.

Front elevation: 5. support for driving mechanism (2); 6. triangular reinforcement; 7. $\frac{3}{4}$ " leveling bolt; 8. horizontal reinforcement; 9. L steel frame, mounted in rubber (4).

III. Column and platform. Elevation and top view (half): 10. stirrer shaft; 11. ball bearing (the same at the upper end); 12. guiding tube for (10); 13. column with triangular thread M 140 $\times$ 1 $\frac{1}{2}$; 14. joint of (12) and (13); 15. lower platform plate, steel, $\varnothing$ 280 $\times$ 10 mm; 16. intermediate platform plate, steel, $\varnothing$ 350 $\times$ 6 mm; 17. upper platform plate, steel, $\varnothing$ 1000 $\times$ 6 mm.

IV. Thermostat. Elevation, partly sectioned: 18. outer jacket; 19. thermometer support; 20. stirrer vane 200 $\times$ 75 mm, with hole $\varnothing$ 30 mm; 21. half spiral shield (36); 22. centre tube $\varnothing$ 85 mm, with reinforced upper edge; 23. heating element; 24. tube for cooling; 25. shield (30); 26. dust cover; 27. stirrer vane for downward flow; the arrow indicates direction of movement; 28. stirrer vane for upward flow; 29. reinforcing ring $\frac{3}{8}$ " $\times$ 1", the same near the bottom of the thermostat. Top view: 30. shield (25); 31. stirrer vane for outward flow; 32. thermostat wall; 33. tube for cooling (24); 34. heating element (23); 35. stirrer vane for downward flow (27); 36. half spiral shield (21); 37. centre tube (22); 38. stirrer vane for inward flow; 39. stirrer vane for upward flow (28).

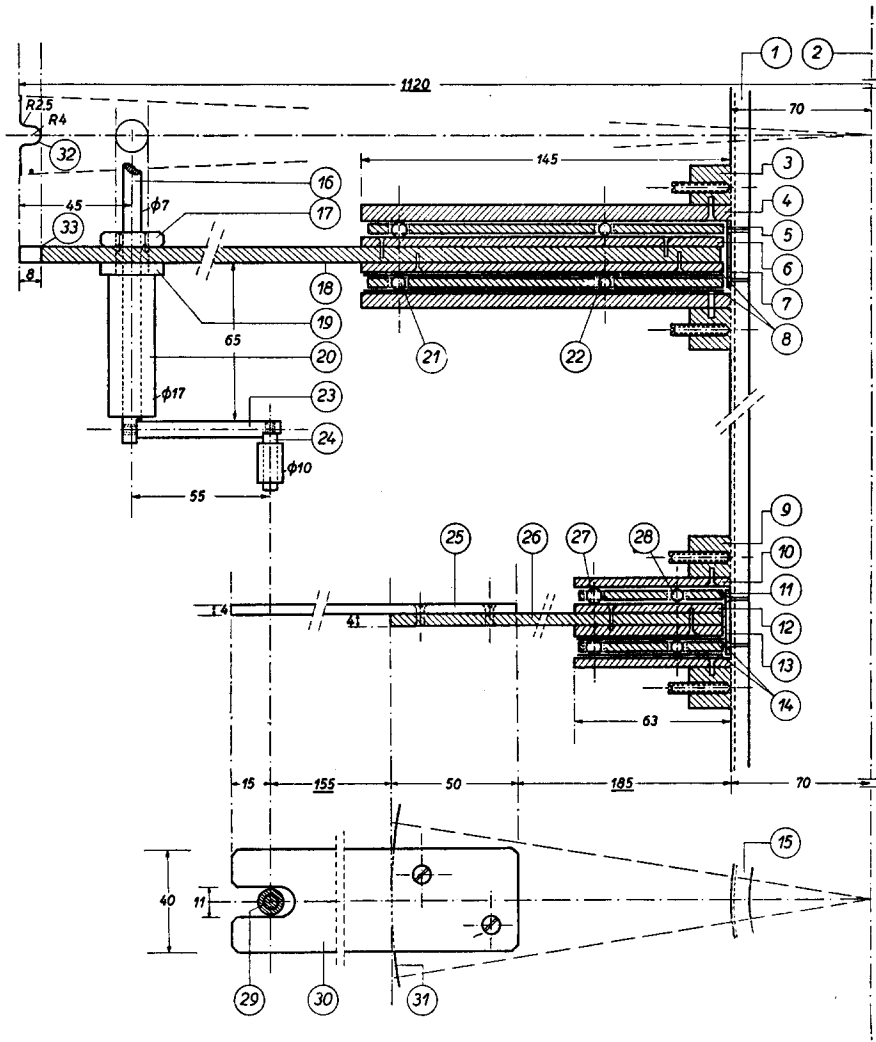


Fig. 4. Manometer plate, shaking plate and bearings (numbers between brackets refer to other views or sections). Scale 1:3.

1. Section through threaded column (Fig. 3 (13)); 2. centerline of column; 3. brass ring, threaded M 1.5, fitting on (1), 4 bolts equally spaced along circumference; 4. brass cover plate of ball bearing, thickness 6 mm thread M 1.5; 5. ball race, aluminium, 3 mm; 6. brass plate, fitting close to 7, thickness 4 mm; 7. brass protection ring on threaded column; 8. 0.8 mm hard stainless steel sheeting; 9. same as (3); 10. brass cover plate of ball bearing, thickness 4 mm, threaded M 1.5; 11. ball race, aluminium, 3 mm; 12. brass plate, fitting close to (13), thickness 4 mm; 13. same as (7); 14. 0.8 mm hard stainless steel sheeting; 15. horizontal section through column; 16. steel shaft for manometer support; 17. hexagonal nut on (20), brass, $\varnothing$ 25 mm; 18. steel manometer plate; 19. ring, fitting on (20), brass, $\varnothing$ 25 mm; 20. brass manometer shaft support with collar $\varnothing$ 13 mm and threaded end $\varnothing$ 11 mm M 1; 21. $\frac{5}{16}$ " balls, 64 equally spaced in outer circle; 22. $\frac{1}{4}$ " balls, 32 equally spaced in inner circle; 23. steel pin, $\varnothing$ 6 mm; 24. steel pin, $\varnothing$ 6 mm, covered with rubber tubing outer diameter 10 mm; 25. forked aluminium plate for shaking mechanism, side elevation; 26. aluminium plate of shaking mechanism; 27. $\frac{5}{16}$ " balls, 48 equally spaced in outer circle; 28. $\frac{1}{4}$ " balls, 32 equally spaced in inner circle; 29. horizontal section through (24) in fork of shaking plate; 30. top view of (25); 31. circumference of (26), shaking plate; 32. top view of circumference of (18), manometer plate recess for shaft (Fig. 5, (42)), 32 recesses equally spaced along circumference; 33. side elevation of (32).

The central hole of 150 mm diameter in the manometer plate (18) is cut out automatically. The upper and lower brass plate (6) fit easily on the brass ring (7), which protects them from damage by the threaded column. The height of (7) is slightly less than the distance between (4) and (8) in running condition. The proper height and the smooth running of the bearings is adjusted by screwing the rings and plates (3, 4) or (9, 10) down- or upwards and fixing them with 4 bolts.

As the outer balls (21, 27) have 5/16" diameter, the inner 1/4" balls (22, 28) take no part in the bearing unless it would be slightly deformed, thus combining mechanical strength and maximal smooth running conditions. The brass plates (4, 6, 10, 12) are protected from damage by the most heavily loaded lower balls by hard steel sheeting (8, 14).

A 1/12 HP 1400 r.p.m. motor is mounted in rubber on the manometer plate and oscillates the shaking plate (26) by means of a worm gear and an eccentric. The current supply for the motor is provided by means of two brushes on the manometer plate and two collecting rings around the column.

The manometers are shaken with the aid of parts (16, 23, 24) of the manometer shaft and the forks (30, 25) on the shaking plate. The frequency can be adjusted in 4 steps from 120 to 180 per minute by means of a rheostat. The amplitude of (24) is normally 9 mm.

When the manometer plate is revolved, the shaking plate is carried along by the gear shaft and the eccentric, so these have to be of a fairly sturdy construction. Details of these parts are shown in Fig. 6.

With regard to the dimensions of the bearing of the shaking plate the distance of the support (Fig. 6, (21)) to the centre line of the column could not be changed enough to adjust the amplitude of shaking of the Warburg flasks over a wide range. An adjustable eccentric was designed by means of which the amplitude could be changed symmetrically.

The outer eccentric (7, 14) can be rotated smoothly round the inner eccentric (10, 16), which is threaded and screwed on the shaft (2). The position of the two eccentric parts is determined by inserting a steel pin, diameter 5.9 mm, in the hole formed by the semicircular recess 1 and one of the inner semicircular recesses 1-7 (16). In the position 1-1 the eccentricity is maximal, in position 1-6 minimal. By means of the clamping plate (11, 15) and the nut (12) the eccentric is fixed between (5) and (11).

D. *Driving mechanism of the manometer plate* (Fig. 5, see also Fig. 2)

When the driving mechanism is coupled by impressing the foot lever, the manometer plate starts revolving and, unless the lever is kept down, automatically stops when the next manometer is in front of the manipulator. With disengaged driving mechanism, oscillation of the manometer plate by the recoil of the shaking mechanism is prevented by a locking device.

The coupling consists of a lower plate II, a middle plate III and an upper plate IV with pulley. Plates II and III are assembled on the support I with a pin (3) and nut through (A). The lever with pawl (7) can move and fix a pin through a guide (6) in a hole in the support (2). The most central hole (I, 4) is in use in the working position of the coupling; when moved to the lateral hole the coupling is completely disengaged and the manometer plate may be turned freely by hand.

Parts III and IV are assembled by a pin with collar (14, 15) through (B); part IV

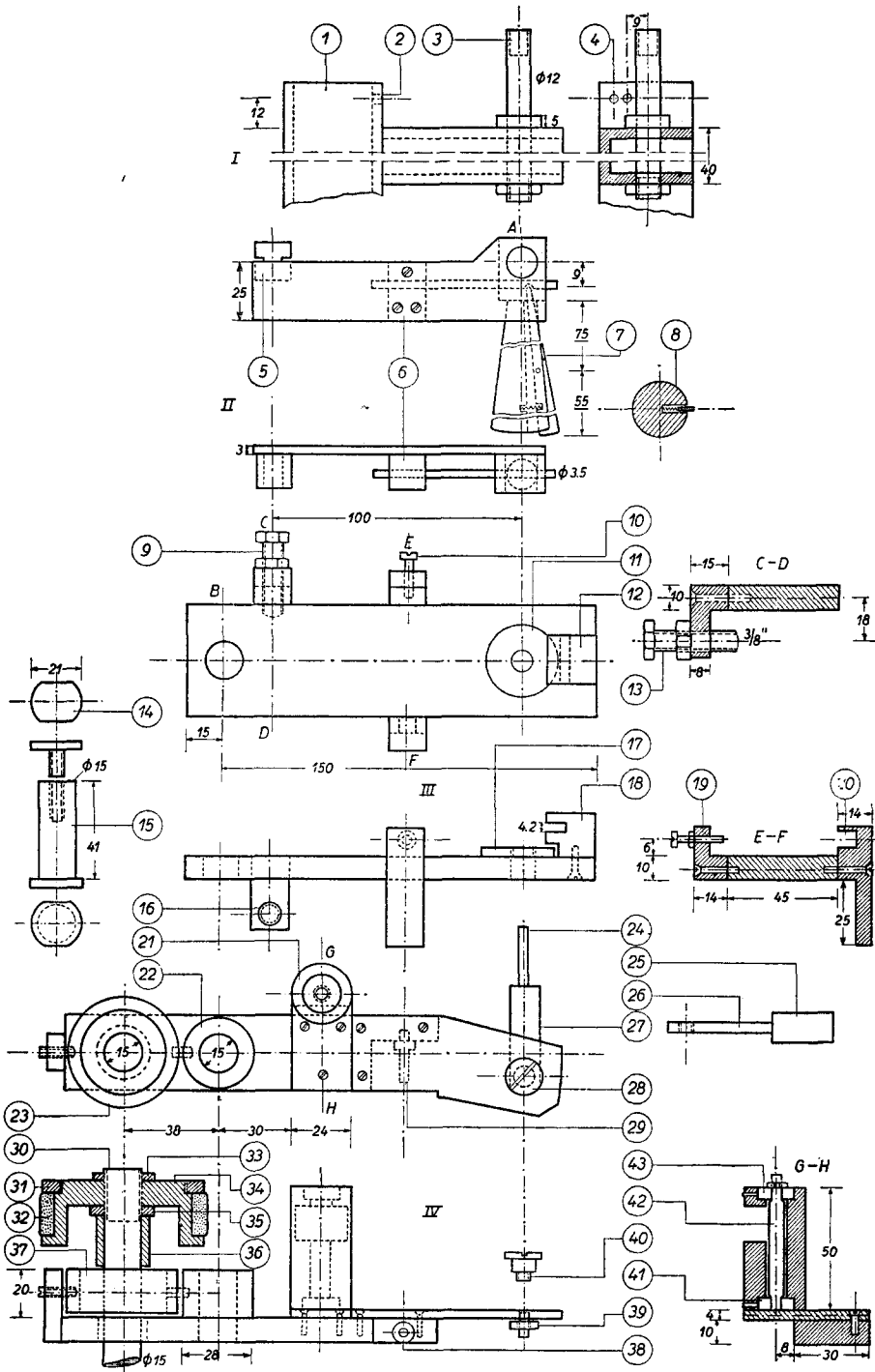


Fig. 5. Driving mechanism of the manometer plate (numbers between brackets refer to other views or sections). Scale 1:3.

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can rotate around this pin. The extreme right part of IV is guided by (12, 18). The lever (26, 27) is attached by a pillar bolt (28) to part IV.

A not too rigid spiral compression spring between (29, 38) and (20) and proper adjustment of (10, 19) presses the shaft (42) of the locking device against the outer edge of the manometer plate. By adjusting the bolt (9, 13) in part III against the rigid circular blade spring inserted in (5), the rubber ring on the rotating pulley (34) is pressed against the outer edge of the manometer plate, so that the latter also revolves. As soon as the shaft (42) clicks into one of the recesses (see Fig. 2 and Fig. 4, (32)) of the manometer plate by the spring tension on (29), part IV rotates around the bolt (15) in (B) and the pulley runs free from the edge. Thus the manometer plate is at one time disengaged and locked. The driving shaft of the pulley has a swinging ball bearing (23, 37) and a universal joint in the shaft is provided (see Fig. 2, (12)).

The lever (27) is coupled to the foot lever on the frame by means of a fork on the flattened part of it (24, 25), and serves to move the shaft (42) of the locking device (21) out of the recess in the outer edge of the manometer plate. At the same time the rubber ring (32) of the pulley is pressed against the outer edge and moves the plate around. If part II is turned to the left (outwards) by the lever (7), the guide (6) presses against the elongation below part III (section E-F), resulting in a movement of part IV, disengaging the pulley as well as the locking device.

For the proper functioning of this mechanism the outer edge of the circular manometer plate had to be machined after the autogenous cutting. This was accomplished by adjusting the plate on the column to the height of centre of the lathe near the tool carrier. By turning the manometer plate carefully by hand and using a flat chisel and a shallow cut, the outer edge could be machined fairly accurately. The necessary weight for keeping the plate in place during this operation was provided by also mounting the thermostat, filled with water.

The recesses were filed to the proper shape after drilling the bottom of the recess.

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- I. Upper part of support for driving mechanism. Front elevation: 1. U steel support (see also Fig. 2 and Fig. 3); 2. holes for locking pin, $\varnothing$ 4 mm; 3. pillar bolt for assembling parts II and III through A; 4. Side elevation, sectioned through A.
 - II. Lower plate of driving mechanism. Top view and front elevation: 5. support with grooves for inserting circular blade spring, compressed by (9); 6. pin guide; 7. lever with pawl, acting on the locking pin through (6) in (2); 8. section through lever.
 - III. Intermediate plate of driving mechanism. Top view: 9. adjusting bolt with check nut; 10. adjusting bolt with check nut; 11. nut for assembling II and III on pillar bolt (3); hole for fixing pin to be drilled after assembling; 12. guide for IV.
Section through C-D: 13. adjusting bolt (9).
Pin for assembling III and IV through B: 14. top view of bolt; 15. pin with collar.
Front elevation: 16. adjusting bolt (9); 17. nut (11); 18. guide for IV.
Section through E-F: 19. adjusting bolt (10); 20. hole for compression spring between 20 and (29), (38).
 - IV. Upper plate of driving mechanism. Top view (pulley omitted): 21. support for locking device; 22. support for (15) and (23); 23. swinging ball bearing $35 \times 15 \times 18$ mm, in brass ring $\varnothing$ 45 mm; 24. flattened end of engaging lever; 25. same as (24), detail, side elevation; 26. engaging lever, side elevation; 27. engaging lever (26), (39), attached with bolt (28) (40) to IV; 28. pillar bolt for attaching (27) to IV; 29. guide pin for compression spring between (29), (38) and (20).
Front elevation, pulley partly sectioned: 30. threaded end of driving shaft; 31. threaded ring; 32. rubber ring; 33. nut; 34. pulley; 35. nut; 36. bushing; 37. swinging ball bearing (23); 38. guide pin (29); 39. engaging lever (26), (27); 40. pillar bolt (28).
Section through G-H: 41. ball bearing $15 \times 5 \times 5$ mm; 42. steel shaft $\varnothing$ 6.5 mm; 43. ball bearing, same as 41.

The apparatus has been in almost continuous use for more than one year without defects and has fully answered expectations.

Blueprints of the original drawings of the apparatus are available for those who seriously consider the construction of a similar instrument.

Our acknowledgements are due to the staff of the laboratory workshop, in particular to Mr W. F. MIJNHARDT and Mr P. A. DE RIDDER, for the great care and ability with which the construction was carried out.

SUMMARY

The construction of a circular Warburg apparatus for 32 manometers is described.

RÉSUMÉ

On décrit la construction d'un appareil Warburg circulaire, pour 32 manomètres.

ZUSAMMENFASSUNG

Beschreibung der Konstruktion eines zirkulären Warburg-Apparates für 32 Manometer.

Received December 12th, 1950