4. S. PALADINO and F. UGOLINI. — A "compensated" stuffing box and bearing unit for fermenters of semiindustrial and industrial capacities.

Summary. — The construction of a stuffing box and bearing unit for fermenters which operates in the culture fluid and is fitted with a pressure compensating chamber has been described. It makes possible the use of high rotational propeller speeds without vibration of the shaft, simplifies the arrangements for power transmission, and conveys greater stability to the fermenter. It ensures freedom from contamination of the fermenter contents by the outside atmosphere through the stuffing material.

Riassunto. — Viene descritto un nuovo complesso di guida e di tenuta per assi ruotanti ad alto e basso numero di giri, applicabile anche ad autoclavi per fermentazioni microbiologiche. Esso è caratterizzato dal fatto di poter essere applicato anche sotto battente liquido, eliminando in tal modo le vibrazioni dell'asse ruotante, semplificando tutto il dispositivo di trasmissione del moto e conferendo maggiore stabilità al fermentatore. Nel caso di applicazioni su cicli speciali di lavorazione la presenza della camera di compensazione garantisce la impossibilità del contatto del liquido contenuto nel fermentatore con l'ambiente esterno.

Résumé. — Les A. déscrivent un système de presse-étoupe, muni des pièces de soutien, destinè aux cuves de fermentations; équipé d'une chambre de compensation à pression, il agit à l'intérieur même du liquide. Ce mécanisme permet de soumettre l'hélice à de hautes vitesses de rotation en éliminant les vibrations de l'arbre; il simplifie les couplages de transmission énergétique tout en augmentant la stabilité de la cuve; il garantit contre toute éventualité de contamination de la part de l'atmosphère ambiante du presse-étoupe.

Zusammenfassung. — Beschrieben wird die Konstruktion einer Stopfbüchse und Lagerung für Gärgefässe, die in der Kulturflüssigkeit arbeitet und mit einer Druckausgleichskammer versehen ist. Hierdurch werden hohe Propellergeschwindigkeiten ohne Vibration der Achse, vereinfachte Kraftübertragung und grössere Stabilität des Gärgefässes.

ermöglicht. Ausserdem wird jedes Eindringen von ungewünschten Mikroorganismen in das Gärgefäss durch die über die Stopfbüchse erfolgende Berührung mit der Aussenluft unmöglich gemacht.

Introduction.

The vortex system of aeration requires higher rotational speeds of the propellers for air dispersion than aeration systems in which an air sparger is employed.

In previous communications (Chain, Paladino, Ugolini, Callow and Van der Sluis, 1954; Paladino, Ugolini and Chain, 1954) stuffing box and bearing units for fermenters of 10, 90 and 300 l capacity were described suitable for both the vortex and sparger system of aeration with propellers rotating at 1500 r.p.m.

The most important performance requirements of fermenter stuffing box and bearing units suitable for vortex and sparger aeration, already briefly indicated in a previous paper (Chain et al. 1954) are listed below:

Bearings:

1) The bearings must be capable of guiding propeller shafts rotating at a number of r.p.m. corresponding to a peripheral speed of ca. 0.1 m/sec. to 1.5 m/sec.

2) Lubrication during the fermentation must be possible without contamination of the culture fluid.

3) The normal working temperature during the fermentation is 24-37° C, but the bearing must also function at a maximum of ca. 130° C during the sterilization of the fermenter and culture medium and a minimum of +2° C at the end of the fermentation.

Stuffing box.

1) The stuffing box must ensure tightness of the fermenter against air, steam and aqueous solutions at 2 atm. overpressure for prolonged periods.

2) It must be constructed in such a way that the pressure of the stuffing material against the shaft can be adjusted during the fermentation which may have a duration of several weeks.

3) The stuffing material must resist the sterilisation temperature of about 130° C plus the heat of friction generated by the rotating propeller shaft.

The stuffing box and bearing units previously described for fermenters up to 300 l capacity fulfil all the above requirements, but attempts to scale them up for use on fermenters of semiindustrial and industrial dimensions were unsuccessful.

As the propeller shaft increases in length — as it must do with increasing fermenter size, if the stuffing box and bearing unit is located at the fermenter head — it becomes increasingly difficult to abolish whip and vibration of the shaft at high rotational speeds and to avoid overheating of the stuffing material owing to excessive friction.

As no easy method could be found to adapt any of the stuffing box and bearing unit systems for use on fermenters of semiindustrial and industrial size to meet with the criteria listed above, the authors have developed a novel stuffing box and bearing system which has proved satisfactory with regard to all these requirements. Its description forms the subject of the present paper.

Principle.

The principle which has served as the basis for the design for the new stuffing box and bearing unit is diagrammatically illustrated in fig. 1.

Two sets of stuffing boxes, one (I) immersed in the culture fluid inside the fermenter and the other (II) outside are separated by a compensation chamber (III) through which sterile air or steam may circulate at a pressure equal to or slightly higher than that prevalent inside the fermenter.

In this way the internal stuffing box I the purpose of which is to safeguard the sterility of the fermenter and its contents is isolated from the atmosphere by a zone which can be kept sterile by the circulation of sterile air or steam; furthermore as the pressure of this zone can be adjusted to that inside the fermenter, stuffing box I does not have to work against a large pressure difference which facilitates its functioning in maintaining a tight seal. In cases where a large pressure difference exists between the inside of the reactor and the atmosphere it

may be desirable to reduce this pressure difference in steps by fitting two or more compensation chambers, with the corresponding number of seals.

Should a defect of the stuffing material in stuffing box 1 develop during the course of a fermentation the sterility of the fermenter contents would still not be endangered. If the pressure inside the compensation chamber is kept slightly below that inside the fermenter small amounts of culture fluid would trickle through the stuffing box into the compensation chamber and be washed away by the steam flow; if, on the other hand, the pressure inside the compensation chamber is slightly above that inside the fermenter, a small quantity of steam will leak through the stuffing box into the culture fluid. In neither case can contamination of the culture fluid occur and the normal course of the fermentation is not interfered with unless the leakage is considerable.

As a part of the new stuffing box and bearing unit operates actually inside the culture fluid it is possible to use much shorter propeller shafts for agitation and air dispersion than in those cases where the stuffing box and bearing unit is located outside the fermenter at the fermenter head and where the propeller shaft has to traverse the air space over the culture fluid.

The principle of using a series of stuffing boxes separated by compensation chambers is not new; it has been applied for instance for the cooling of bearings of naval and aeronautical turbines (Baulino, 1950; Godsey Jr. and Young, 1949). However, as far as the authors are aware no application of this principle to the field of fermentation has so far been described.

Some agitation systems for fermenters have been employed industrially for which the stuffing box and bearing unit was located at the bottom of the fermenter. These systems, however, are not adaptable for high rotational propeller speeds, and, even at low propeller speeds, do not provide an absolute guarantee against the risk of contamination.

Description of stuffing box and bearing unit for 300 l fermenter

Location.

The unit is screwed by means of the upper external thread on housing 1 fig. 2 (for details see 1 fig. 2-a) to the internally threaded flange 11 fig. 2 (for details see 11 fig. 2-c) welded centrally to the fermenter bottom. A gasket of asbestos or other heat resistant material is placed between this flange and the appropriate flange on housing 1.

Components.

The unit consists of two components, one fixed to the fermenter, the other adjustable within the fixed component.

a) *Fixed component.*

This part comprises the shell 1 fig. 2 (for details see 1 fig. 2-a), to which is tack-welded cylinder 16 (for details see 16 fig. 2-e), the cylindrical cap 10 fig. 2 (for details see 10 fig. 2-c) compressing the first series of packing rings, and the lock ring 17 fig. 2 (for details see 17 fig. 2-e).

Cylinder 16, made of brass, is internally threaded for carrying the adjustable component; it is made of a different metal from that used for part 1 (which is made from stainless steel) in order to avoid seizing of the adjustable component (which is also made from stainless steel) against the fixed component.

The cylindrical cap 10 fig. 2 is externally threaded and screwed by means of a pin spanner into the upper internal thread of shell 1 fig. 2 with the interposition of a gasket of asbestos or other heat resisting material.

Two holes A and B fig. 2 (for details see A and B fig. 2-a) diametrically opposite to each other are bored into shell 1 fig. 2 into which two short tubes for connection with the air or steam line are welded.

Adjustable component.

This part consists of the internal housing 5 fig. 2 (for details see 5 fig. 2-b) accomodating the second and third series of stuffing rings as well as spring 6 fig. 2 which serves to compress them, the two cups 2 fig. 2 (for details see 2 fig. 2-a) in which spring 6 is held, the cylinder 8, 9 and 12 (fig. 2) containing the first, second and fourth series of stuffing rings, the lock rings 13 and 14 (fig. 2) and the short cylinder 15 fig. 2.

Internal housing 5, carrying cylinders 8 (screwed to its upper internal thread), 9 (held by two pins fixed on its upper shoulder) and 12 (screwed to its lower internal thread) as well as the upper and lower ball bearings is screwed by means of its internal thread to shell 1 of the fixed part. In this way the first series of stuffing rings are compressed to the desired degree. Their function is to seal off the fermenter

contents against the outside atmosphere. The position of housing 5 at the desired level inside shell 1 is blocked by lock ring 17.

The outer race of the upper ball bearing is blocked between the internal lower shoulder of cylinder 8 and the upper end of cylinder 9 while the inner race is a tight fit on the shaft. The space between the lower face of the upper internal shoulder of cylinder 8 and the upper face of the upper shoulder of cylinder 9 serves as a grease chamber, the grease being introduced through a central hole 20 fig. 2 on the propeller shaft.

The compensation chamber is formed by the space between the second and third series of stuffing rings the purpose of which is to protect the bearings against steam. They are automatically compressed by spring 6 contained in the two cups 2 fig. 2, against the lower face of the internal shoulder of cylinder 9 and the upper face of the middle shoulder of internal housing 5. The two cups 2 fig. 2 are each held by three pins (3 fig. 2, for details see 3 fig. 2-a) projecting from their external walls and sliding in appropriate slots cut into housing 5.

The outer race of the lower ball bearing is blocked between the lower internal shoulder of housing 5 and the upper end of cylinder 12. Cylinder 12 is blocked against housing 5 by rotating lock ring 14 fig. 2 on the middle thread of cylinder 12 against an asbestos gasket. The inner race of the lower ball bearing is blocked between a shoulder on the propeller shaft and ring and lock ring 4 fig. 2 (for details see 4 fig. 2-a). The space formed by the lower face of the middle shoulder of housing 5 and the upper face of the shoulder of cylinder 12 provides a grease chamber to which grease is supplied through hole 21 fig. 2 and the channel connected to it drilled in the lower end of housing 5. After introduction of the grease hole 21 is closed by means of a screw and washer.

The fourth series of stuffing rings the purpose of which is to avoid the leakage of grease from the lower ball bearing, is held between the lower face of the shoulder of cylinder 12 and the end of the internal ring of cylinder 15. Compression of the stuffing rings to the desired degree is effected by rotating cylinder 15 fig. 2 (provided with an internal thread on its external ring) (for details see 15 fig. 2-d) on the external lower thread of cylinder 12, after which cylinder 15 is blocked in position by means of lock ring 13 fig. 2 (for details see 13 fig. 2-d). Lock rings 13 and 17, cylinder 15 and housing 5 are provided with handles 19 fig. 2 (for details see 19 fig. 2-e).

The propeller shaft is constructed in two parts 7 fig. 2 and 18 fig. 2

(for details see 7 fig. 2-b and 18 fig. 2-e) to enable the drilling of a central channel for the grease supply to the upper bearing. After drilling a channel in each part they are screwed into each other and welded at the joint. After the introduction of the grease, hole 20 fig. 2 is closed by means of a screw and a washer.

The upper part of the propeller shaft is externally threaded to fix the propeller against a shoulder on the shaft by means of a nut while the thread on the lower part serves for locking the pulley in position, also by means of a nut.

The centre of the shaft is provided with a shoulder against which the inner race of the lower ball bearing is held and a thread below this shoulder for the ring and the lock ring 4 blocking the inner race in position (see above).

Stuffing material.

Stuffing rings of appropriate diameter with square section (width 6 mm) of the « Triplex Star » type which had been successfully used on the stuffing boxes of the smaller fermenters, (Chain *et al.*, 1954) and, after much experimentation, were also found to give the best results on the compensated stuffing box and bearing unit, were exclusively fitted.

The number of stuffing rings employed for the different seals varied according to the duties they had to perform in different positions and can be seen from fig. 2. Compression of the stuffing material to ensure a tight fit was effected in some cases by hand by means of threaded caps, in others the pressure was automatically maintained by springs. In the latter case it was ascertained by means of the static pressure balance formula (*) $p_E = p_I \, e^{2fh/w}$ that the tension of the springs employed exceeded the theorical minimum value p_E by a sufficient safety factor.

(*) p_E = absolute external pressure required for compression of the stuffing material to balance p .

p_I = absolute internal pressure exerted by the gas and/or the liquid inside the fermenter against the stuffing material. (For the fermenters used by the authors a value of 4 atm. was assumed).

f = dynamic friction coefficient between stuffing material and shaft.

h = total height of stuffing material in the stuffing box.

w = width of cross section.

For the calculation p_I was taken as 4 atm. f was determined experimentally by dynamometric measurements for the « Triplex Star » stuffing rings and found to be 0.05-0.06. The value remained unchanged with use. w was 6 mm. The values for h for the different seals are indicated in the appropriate figures.

CONSTRUCTION OF STUFFING BOX AND BEARING UNIT FOR 3000 l FERMENTER.

The construction of a stuffing box and bearing unit for larger fermenters (3000 l capacity and above) is illustrated in fig. 3. It is similar in design to that of the smaller unit described above.

Components.

The unit is made of two fixed and five adjustable parts, the latter regulating the pressure of the stuffing material.

Upper fixed part.

The upper fixed part is bolted to the end flange of a cylinder which is welded through the fermenter jacket to the centre of the fermenter bottom. It contains an upper and lower ball bearing and five series of stuffing rings.

Lower fixed part.

The lower fixed part (1, 2, 3, 4, 13, 16, 42 fig. 3) supports the lower bearing thus providing additional stability to the whole unit. The cylindrical housing 1 containing an additional ball bearing is fitted to the fermenter bottom by 6 T section angle iron supports.

Stuffing rings and compensating chamber.

Five series of stuffing rings are provided.

The first series seals off the interior of the fermenter. The second series protects the upper ball bearing from steam. This and the third and fourth series form the compensation chamber. The fourth series of stuffing rings protects the lower ball bearing from steam while the fifth series prevents leakage, e.g. of grease from the lower ball bearing.

The compensation chamber is divided into two parts (A and B) by the third series of stuffing rings. During the sterilisation period steam is passed through both parts. At the end of the sterilisation the steam supply to the upper part is cut off in order to prevent excessive heat transfer into the culture medium while sterility of the fermenter contents and the upper part of the compensation chamber is maintained by continuing the steam flow or passing a flow of sterile air through the lower chamber.

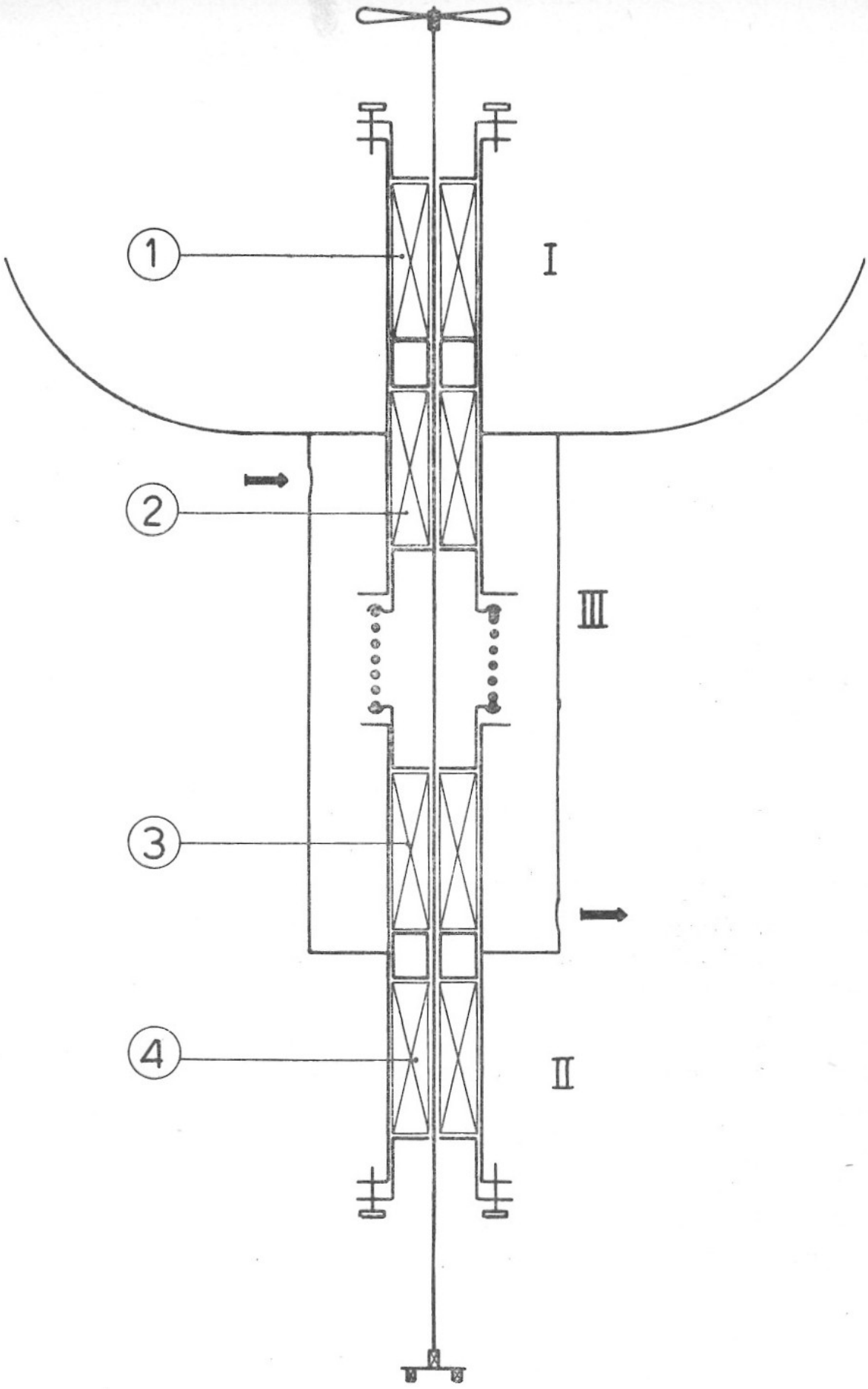

Fig. 1 - Schematic diagram of compensated stuffing box and bearing unit.

I) Upper set of stuffing boxes (1 & 2) immersed in culture fluid.
II) Lower set of stuffing boxes (3 & 4) outside the fermenter.
III) Compensation chamber.

Fig. 2 - Compensated stuffing box and bearing unit for 300 l fermenter. Cross section.

Component	*N. of pieces*	*Material*
1) External housing (Shell).	1	Stainless steel
2) Cylindrical cups for transmission of spring pressure to stuffing rings.	2	» »
3) Guide pins.	6	» »
4) Lock rings.	2	» »
5) Internal housing.	1	» »
6) Spring.	1	Piano wire diam 2.5 mm n° of turns 9, max. load 14 Kg.
7) Propeller shaft (lower part).	1	Stainless steel
8) Stuffing box cylinder.	1	» »
9) » » »	1	» »
10) Cap for compressing stuffing rings.	1	» »
11) Flange.	1	» »
12) Stuffing box cylinder.	1	Mild steel
13) Lock ring.	1	Brass
14) » »	1	Mild steel
15) » »	1	Brass
16) External housing (lower part).	1	»
17) Lock ring.	1	»
18) Propeller shaft (upper part).	1	Stainless steel
19) Handles for lock rings.	8	Mild steel
20) Grease hole for upper bearings.		
21) Grease hole for lower bearing.		

The stainless steel used was of the type: Cr 18 =, Ni 8 =, C 0.08 %, Mn 2 %.

A « compensated » stuffing box and bearing unit for fermenters of semiindustrial and industrial capacities.

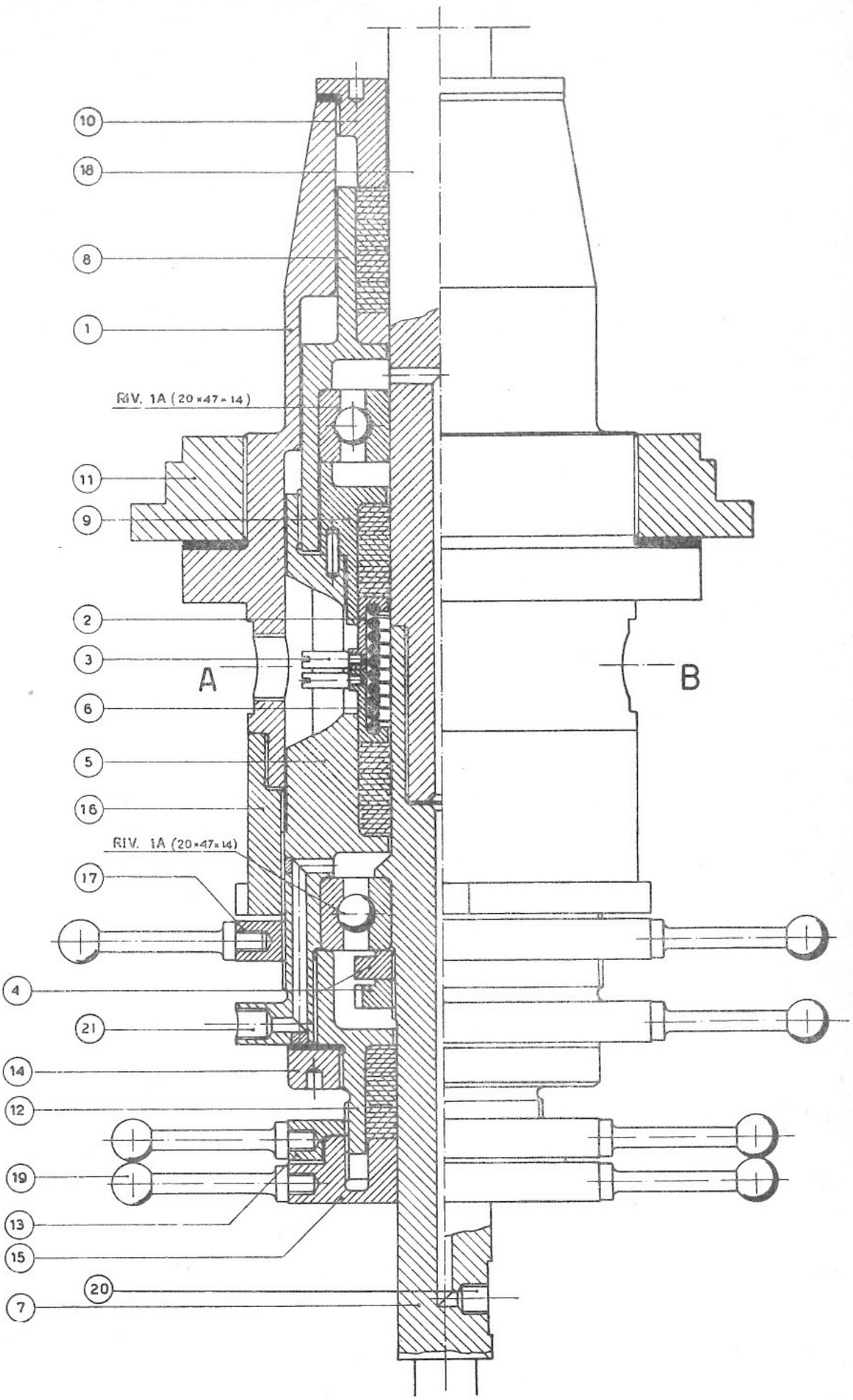

Fig. 2.

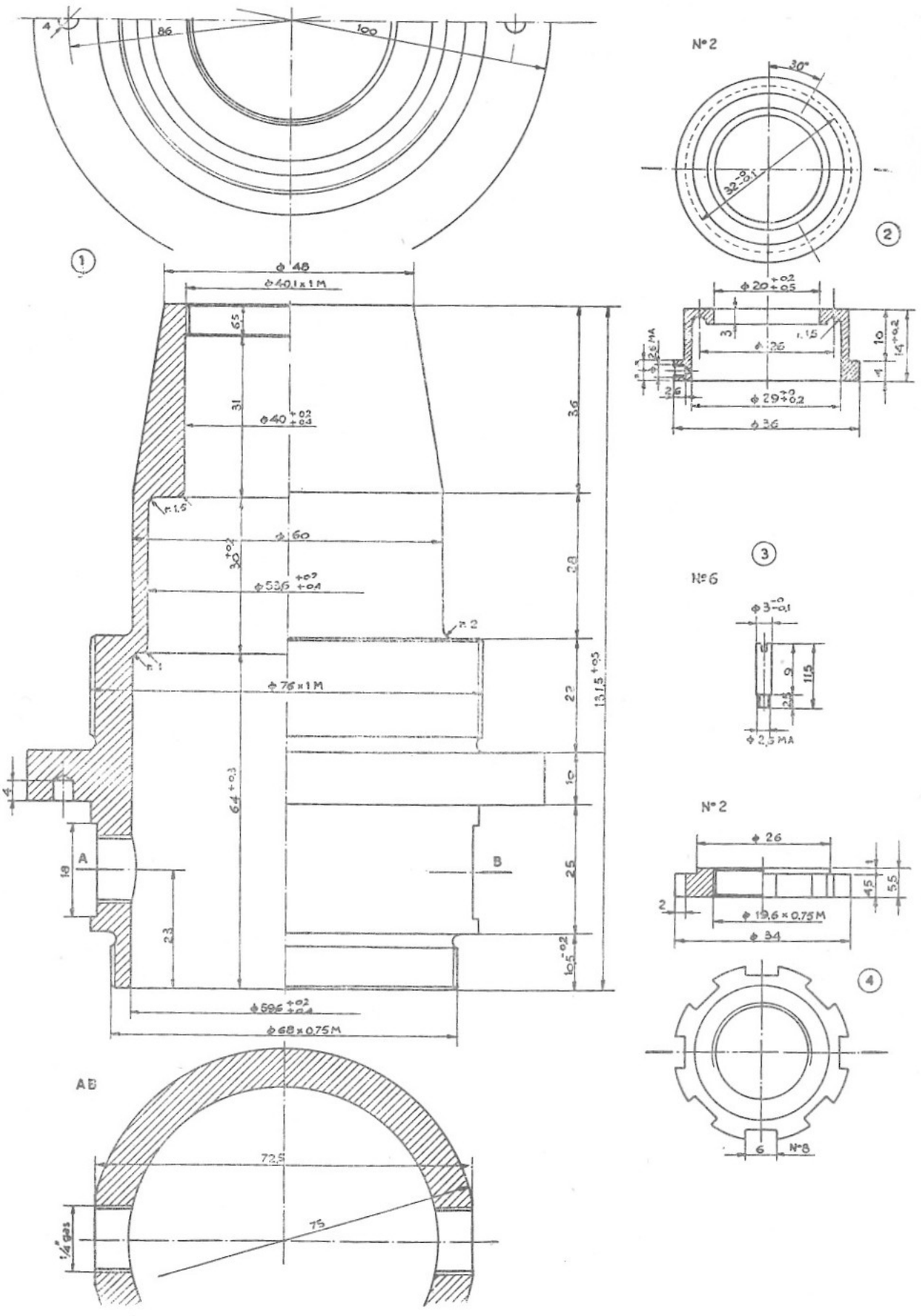

Fig. 2-a. - Details of Fig. 2 components 1-4.

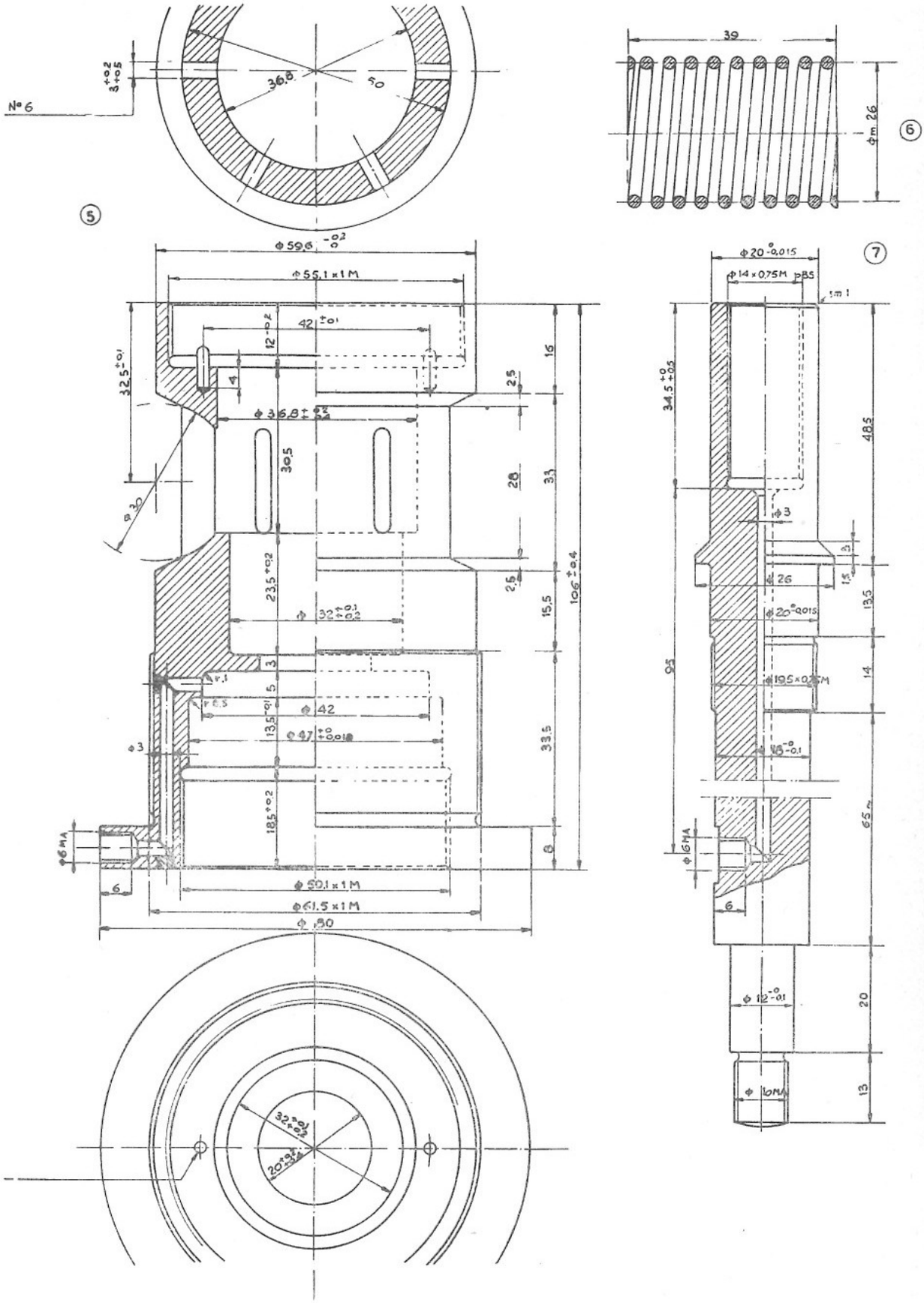

Fig. 2-b. - Details of Fig. 2 components 5, 6, 7.

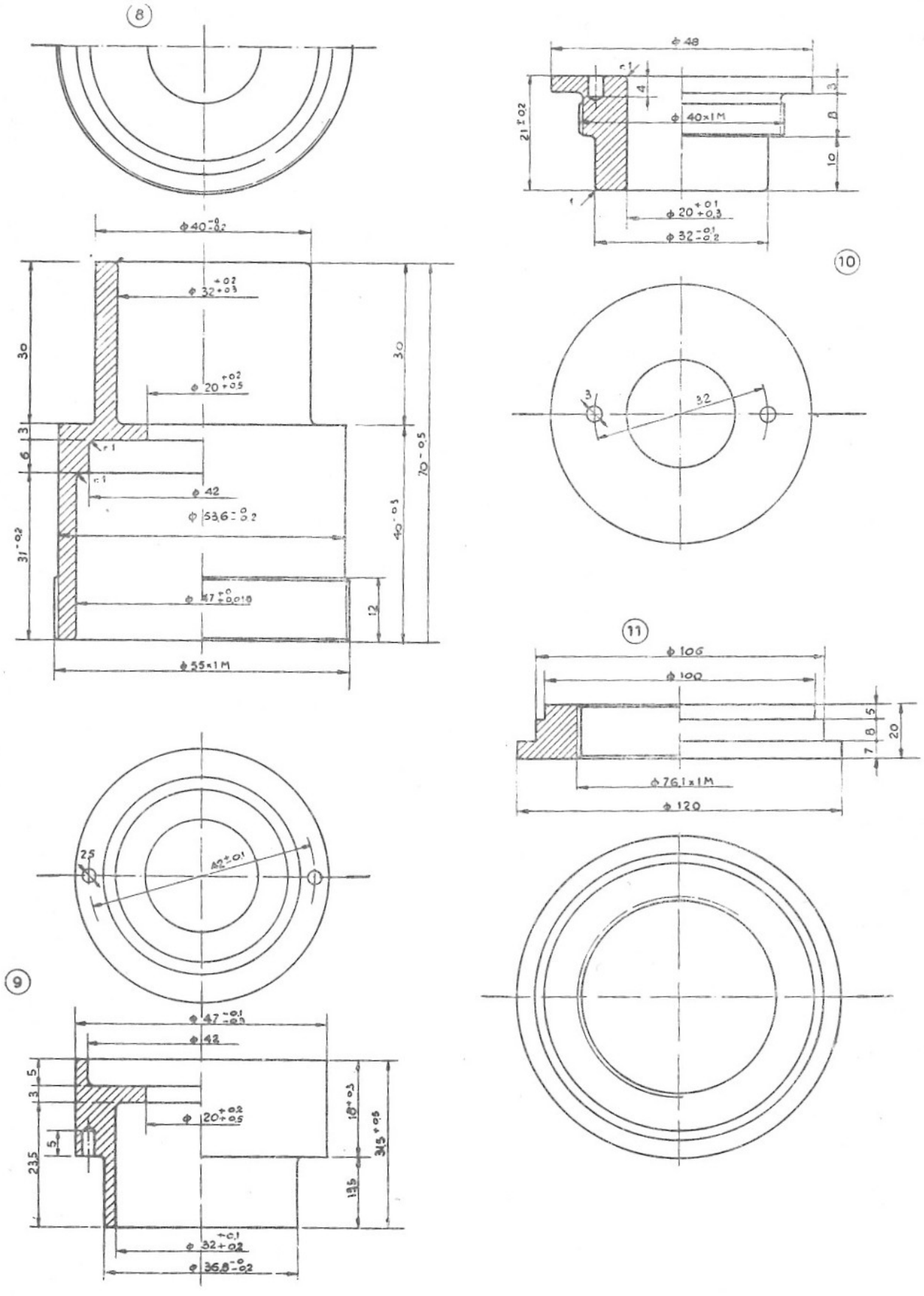

Fig. 2-c. - Details of Fig. 2 components 8-11.

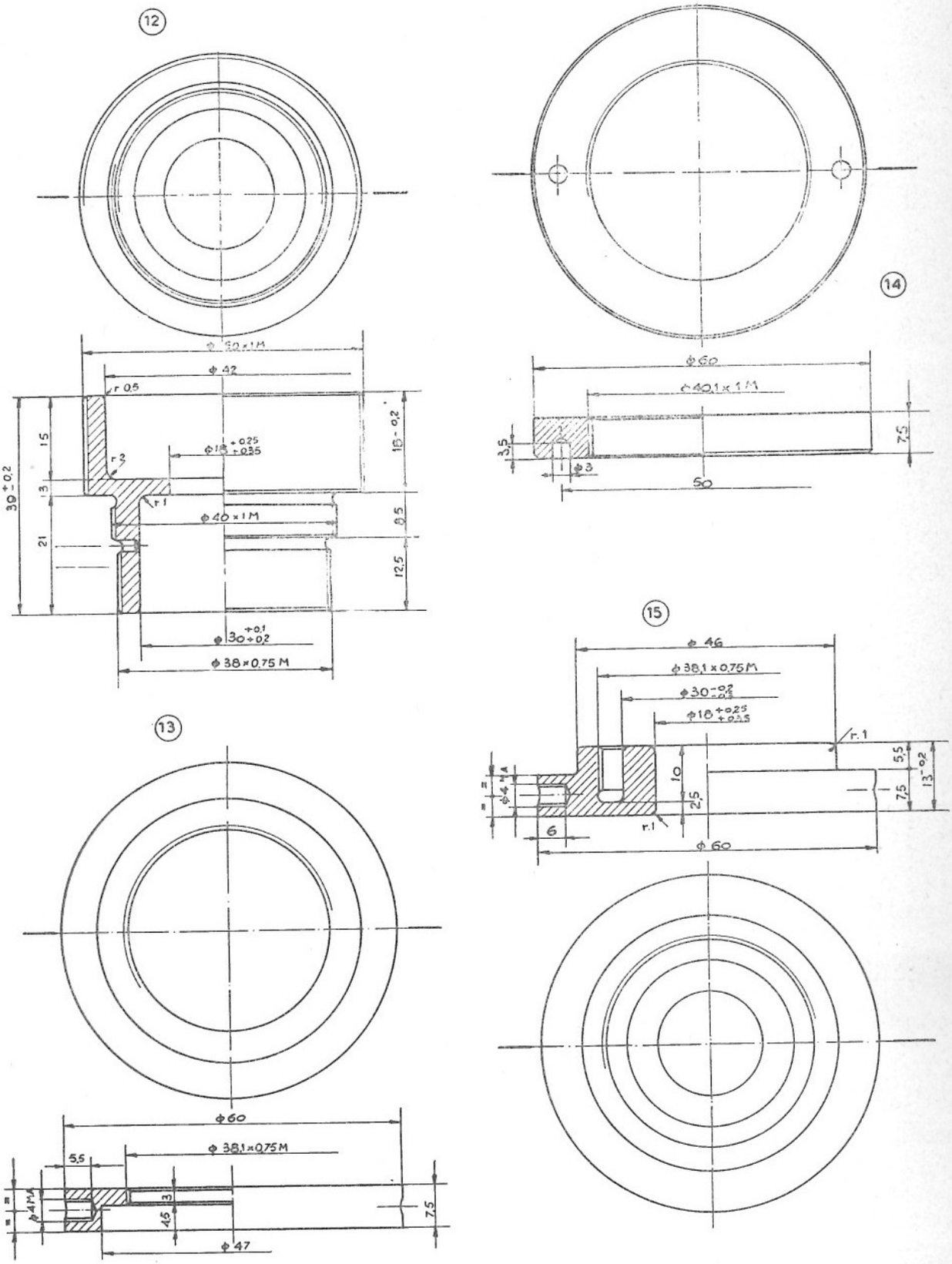

Fig 2-d. - Details of Fig. 2 components 12-15.

Fig. 2-e. - Details of Fig. 2 components 16-19.

A «compensated» stuffing box and bearing unit for fermenters of semiindustrial and industrial capacities.

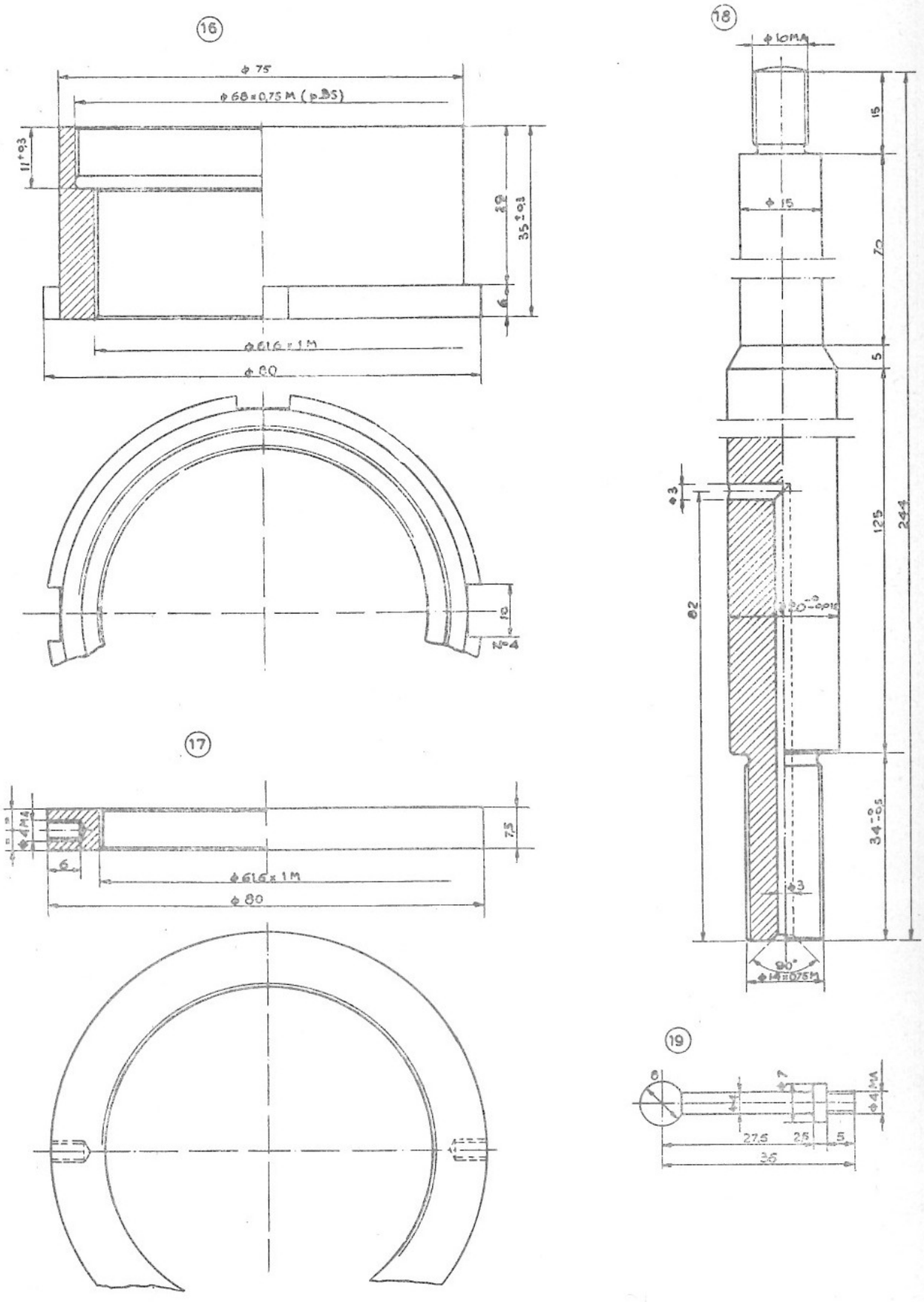

Fig. 2-e

Fig. 3. - Compensated stuffing box and bearing unit for 3000 l fermenter.

Cross section.

1) Housing for bottom bearing.
2) Bolts fixing bottom bearing housing to support.
3) Washer.
4) Spacers for adjustment of bearing housing.
5) Collar.
6) Ring and lock ring.
7) Sleeve.
8) Ring and lock ring.
9) Stuffing box cylinder.
10) Stuffing box cylinder and lower bearing housing.
11) and 12) Cap for compressing stuffing rings, made in two parts, (1) threaded and (12) bolted to (11). *
13) Flange.
14) Cylinder welded through fermenter and jacket.
15) Fixing bolts for main housing.
16) Cover plate for grease chamber of bottom bearing.
17) Propeller shaft.
18) Main housing.
19) Stuffing box.
20) and 21) Cylindrical cups for transmission of spring pressure to stuffing ring.
22) and 23) Guide pins.
24) Stuffing box.
25) Seating for spring.
26) Collar.
27) Blocking ring.
28) Guide cylinder for cylindrical cup (33).
29) Pins for fixing spring seatings.
30) and 31) Upper cap for compressing stuffing rings made in two parts, (30) threaded and (31) bolted to (30). *
32) Stuffing box cylinder.
33) Cylindrical cup for transmission of spring pressure to stuffing rings.
34) Bolts fastening (31) to (30).
35) Propeller.
36) Boss carrying propeller.
37) and 38) Springs.
39) Bolts and nuts for holding propeller to flange.
40) Fixing bolts uniting upper and main parts of housing.
41) Exit hole for grease.
42) Fixing bolts for cover plates of bottom bearing.
43) Fixing bolts uniting lower and main parts of housing.
44) Bolts fastening (12) to (11).
45) Screw closing grease entry.
46) Pin closing grease exit hole and blocking (26) against (32).

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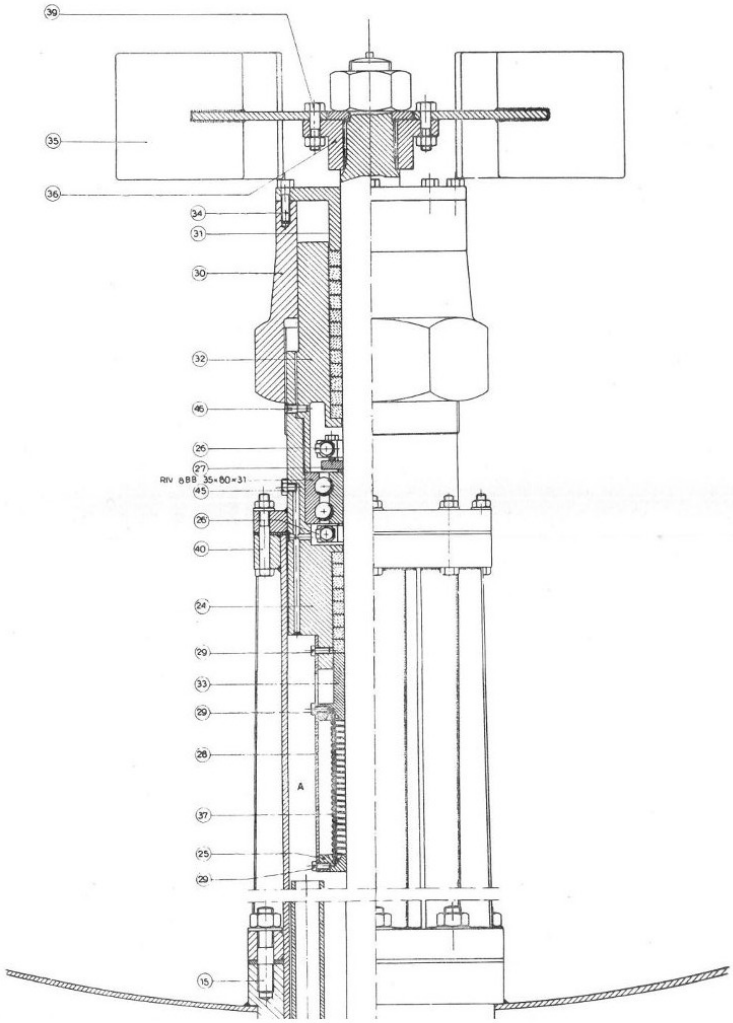
* This arrangement is made in order to make possible the replacement of stuffing rings without dismantling the bottom bearing or propeller.

A « compensated » stuffing box and bearing unit for fermenters of semiindustrial and industrial capacities.



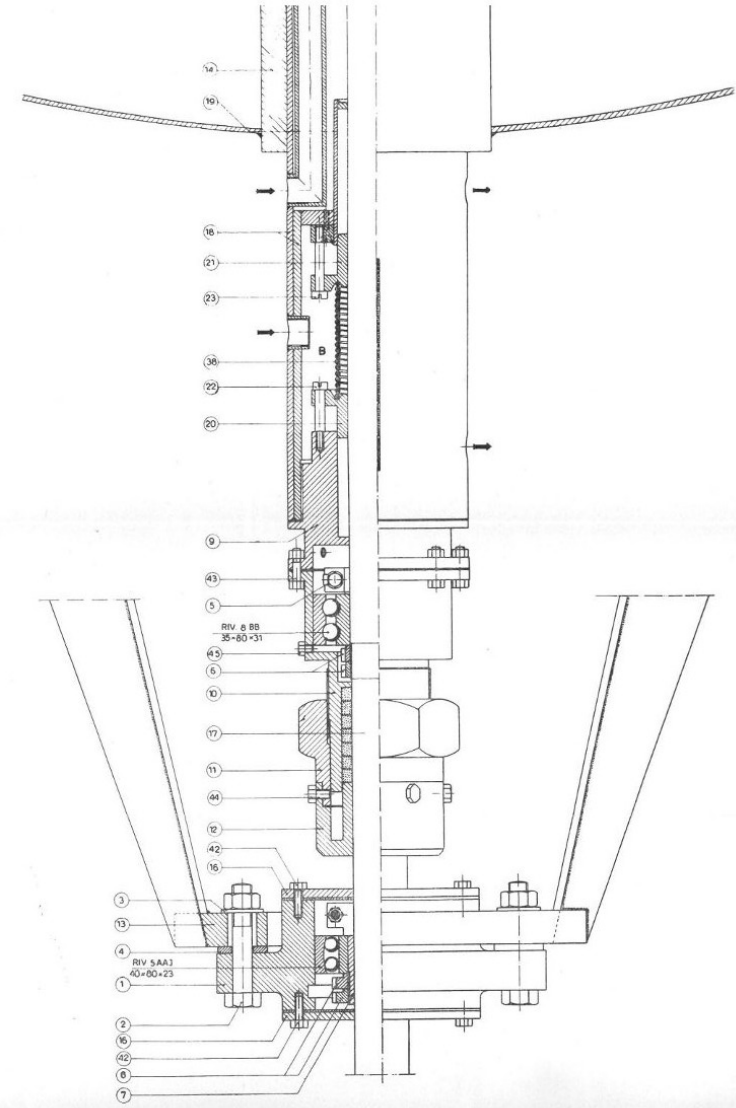
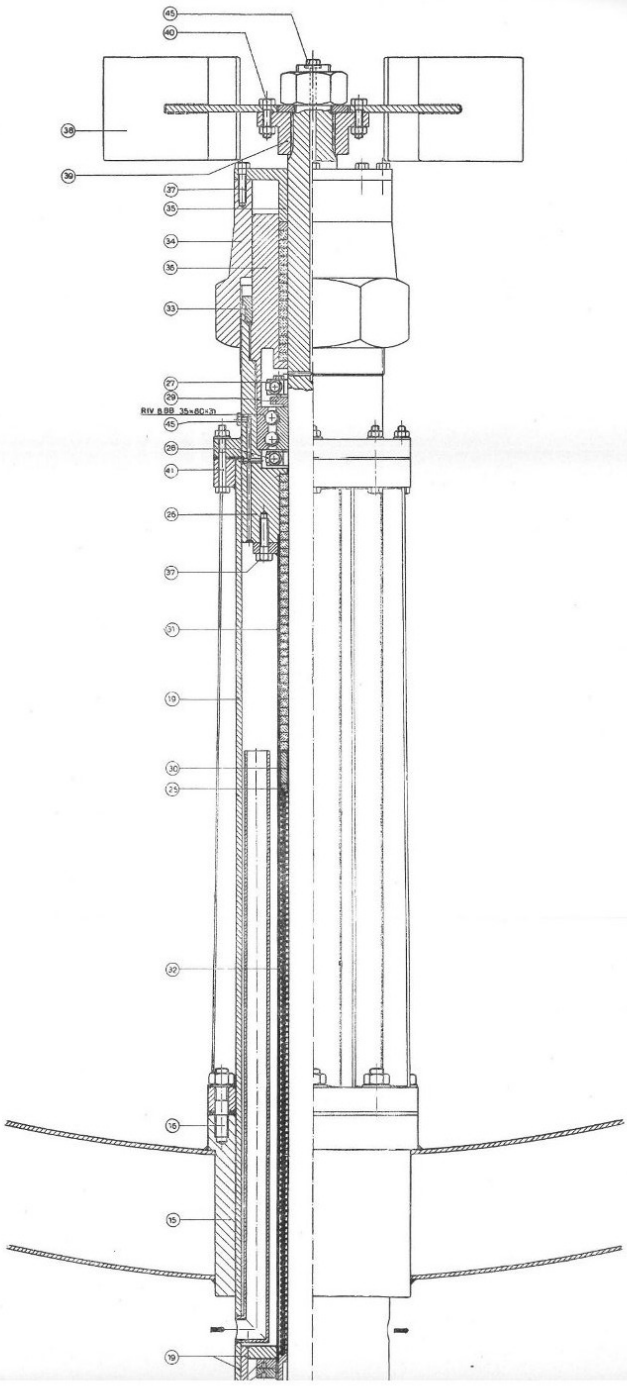


Fig. 3.

Fig. 4. - Simplified compensated stuffing box and bearing unit for 3000 l fermenter. Cross section.

1) Housing for bottom bearing.
2) Bolt fastening housing of bottom bearing to support.
3) Washer.
4) Spacers for adjustment of bearing housing.
5) Collar.
6) Ring and lock ring.
7) Sleeve fastened to shaft with - 7-*b*) Screws.
8) Ring to block inner race of bottom bearing.
9) Locking cylinder.
10) and 11) Stuffing box cylinders.
12) and 13) Cap for compressing stuffing material, made in two parts, (12) threaded and (13) bolted to (12). *
14) Flange.
15) Cylinder welded through fermenter and jacket.
16) Fixing bolts for main housing.
17) Cover plate for grease chamber of bottom bearing.
18) Propeller shaft.
19) Main housing reinforced inside fermenter with struts and outside fermenter by double wall.
20) Bolts fastening stuffing box extension (22) to stuffing box cylinder (10).
21) Cylindrical spacer for drainage.
22) Stuffing box extension.
23) Ring and lock ring for making a steam-tight seal between compensation chambers A and B.
24) Cylindrical cup transmitting spring pressure to stuffing material.
25) Spring seating.
26) Stuffing box cylinder.
27) and 28) Collars.
29) Blocking ring.
30) Cylinder for transmission of spring pressure to stuffing material.
31) Cylinder preventing communication between the two compensation chambers A and B and protecting spring and stuffing material against steam.
32) Spring.
33) Blocking ring between stuffing box cylinder (26) and stuffing box cylinder (36).
34) and 35) Cap for compression of stuffing material, made in two parts, (34) threaded and (35) bolted to (34). *
36) Stuffing box cylinder.
37) Bolts fastening parts 34 and 35.
38) Propeller.
39) Boss carrying propeller.
40) Bolts fastening propeller to flange.
41) Bolts fastening upper part to main part of housing.
42) Bolts fastening cover plates of bottom bearing housing.
43) Bolts fastening lower part to main part of housing.
44) Bolts fastening (13) to (12).
45) Screw closing grease channel for upper and lower bearing.

* See footnote under fig. 3.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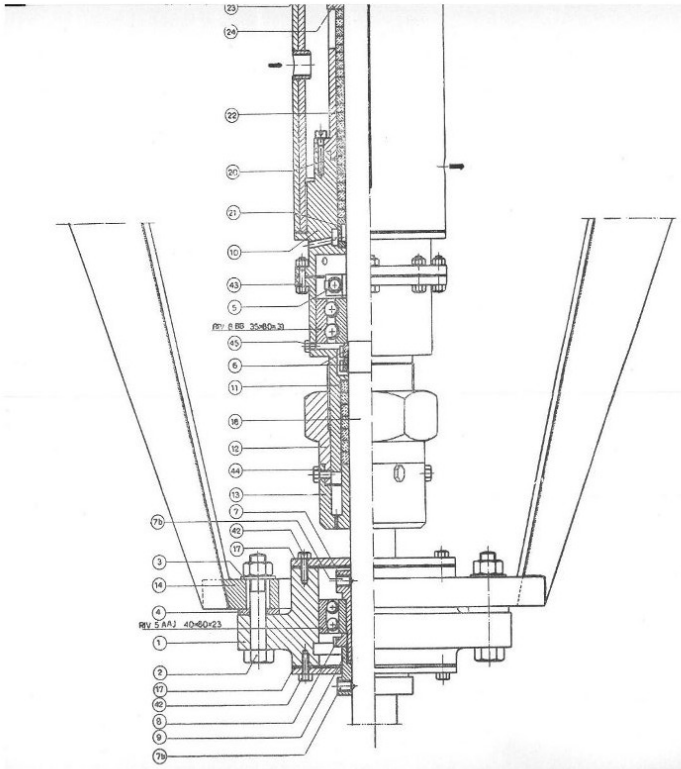
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Fig. 4.

Compression of stuffing rings.

Compression of the stuffing rings is effected by five adjustable parts.

The pressure of the first and fifth series of stuffing rings is adjusted manually by two cylindrical caps (upper cap 30, 31, 34; lower cap 11, 12, 44). The pressure of the second, third and fourth series of stuffing rings is maintained automatically by means of two springs the pressure of which is conveyed to the stuffing rings by the ends of three cylindrical elements (33, 21 and 20) which slide on appropriate guides (28, 23, 22).

Blocking of bearings.

The way adopted to block the inner and the outer races of the three ball bearings is selfexplanatory from the figure.

Propeller shaft.

The propeller shaft (17) is threaded at the upper end to take the propeller, and at the height of the second ball bearing to take a ring and lock ring in order to block the inner race of the lower ball bearing against the collar (5). To its lower end a pulley is fixed appropriately.

Lubrication.

The upper ball bearing is lubricated through a channel closed by screw (45). An outlet for the grease is provided closed by screw (46).

The lower ball bearing is lubricated in a similar way.

The external ball bearing is lubricated after removing cover plate 16. A suitable high-melting mineral grease was used.

VARIANT OF STUFFING BOX AND BEARING UNIT FOR 3000 l FERMENTER.

Fig. 4 represents a simplified variant of the compensated stuffing box and bearing unit described above. In this model the number of series of stuffing rings is reduced to four, and only one spring is used for automatic pressure regulation.

The compensation chamber is formed by two independent compartments A and B separated from each other by the cylinder 31.

Steam is passed through the upper compartment A only during the sterilisation while the lower compartment B is kept under steam continuously throughout the fermentation.

Lubrication of the upper ball bearing is effected through a channel bored into the centre of the propeller shaft. The other two bearings are lubricated as described above.

Wear of the stuffing rings can be detected by the escape of steam through a channel drilled into cylinder 10 just below the third series.

A minor modification of the blocking arrangement of the inner race of the bottom ball bearing in the lower fixed part has been made.

DISCUSSION

The above described stuffing box and bearing units for fermenters of 300 and 3000 l capacity have been in continuous use in this laboratory for a period of over two years in the case of the smaller unit and for a period of one year in the case of the larger unit.

Their performance has been entirely satisfactory with regard to mechanical reliability and their capability to maintain sterility.

The advantage of the new compensated unit over the conventional models are briefly summarized as follows.

1) More even distribution of the friction of stuffing material against the rotating shaft; consequently less development of heat without local overheating and less wear.

2) Simplification of design of the power transmitted directly by V-belts and appropriate pulleys without a need for reduction gears.

3) With the stuffing box and bearing unit operating within the culture fluid a much shorter propeller shaft may be used and the motor may be mounted on the floor. Thus the danger of vibration and whip of the shaft, even with high rotational speeds, is much reduced, the need for a special scaffolding at the top of the fermenter for motor and gears is abolished, and a greater mechanical stability is conferred to the whole fermenter.

4) The presence of a pressure compensating chamber facilitates the maintenance of tightness by the internal seal which does not have

to work against a large pressure difference inside and outside the fermenter.

5) The compensation chamber acting as a continuously operating steam or sterile air seal excludes the possibility of contamination of the culture medium by the outside atmosphere through a leakage in the stuffing box.

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