

TECHNICAL FEATURES OF LARGE VERTICAL CONCRETE VOLUTE PUMPS

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ABSTRACT

A summary of the current technique of concrete volute pumps, a technique which is widely used in several countries (Germany, Great Britain, Italy, Netherlands, Portugal, South Africa, the Soviet Union and, more particularly, in France) is presented. The hydraulic performance obtained and the wide range of possible applications are mentioned. The main components of this type of pump and materials employed are described and the fundamental simplicity of this technology is highlighted. The advantages of concrete volute pumps are examined, including high reliability, maximum availability, low maintenance costs, excellent corrosion resistance, very little micro- or macrofouling and vibration free behavior.

The strong points of concrete volute pumps versus conventional vertical wet pit pumps are presented in a comparative table. A quick look at the many possible areas of application gives the assurance that the use of such pumps will continue to grow.

INTRODUCTION

Concrete volute pumps may be used in any place where pumping relatively high flowrates of fresh or saline water is required. The first concrete volute pump in the world was installed in 1917, for raising sea-water in harbor basins in Saint Nazaire (France). This pump was designed for a flowrate of 6 m³/s (95,000 gpm) and a total head of 3.3 m (10 ft). It is still operating in satisfactory condition.

This first concrete volute pump was designed because of the lack of steel during the First World War. Its very satisfactory behavior, especially with sea water, promoted usage of the same type of pump for thermal power stations, ports and ship building sites and sea water pumping stations, built in France before 1970 [1,2]. These installations proved the very high reliability of this type of pump. From this period, flowrates required by power stations and big industrial complexes became larger and larger. The concrete volute pump was an interesting alternative to large steel casings which could no longer be made in a foundry and would have led to high transport costs. The concrete volute may be easily constructed by any local civil engineering company, anywhere in the world [3].

Its ability to pump very high flowrates with a very high reliability resulted in this type of pump being chosen for cooling water circuits of recent French 900 MW and 1300 MW nuclear electric power generation plants. Approximately 120 concrete volute pumps have been recently constructed in these nuclear plants, with a unit flowrate greater than 20 m³/s (300,000 gpm) per pump. In these plants, only two 50 percent duty pumps are installed without stand-by units due to the high availability of these pumps. Their average availability coefficient calculated over a 10 year period has been 99.95 percent [4]. During these years of development, the concrete volute pump has been continuously improved to obtain higher hydraulic performance as well as lower investment and maintenance costs. The main technical features and many practical advantages of this type of pump are presented herein.

THE PRINCIPLE OF CONCRETE VOLUTE

The layout in Figure 1 shows how the concrete volute casing may be integrated within civil engineering construction of the pumping station. Compared with conventional axial or mixed flow sump pumps, the concrete volute pumps present the following advantages:

- much lower weight and cost of metal parts for the same concrete volume (cost reduction is often more than 30 percent). Moreover, the number and dimensions of grouted parts have been reduced as much as possible
- lower crange height and lifting capacity requirements.
- high corrosion and erosion resistance of the pump casing, more particularly in saline water.
- no vibration, no noise, no external fouling, no maintenance of the casing.
- full accessibility—easy internal inspection without dismantling the pump. For pumps with a capacity higher than

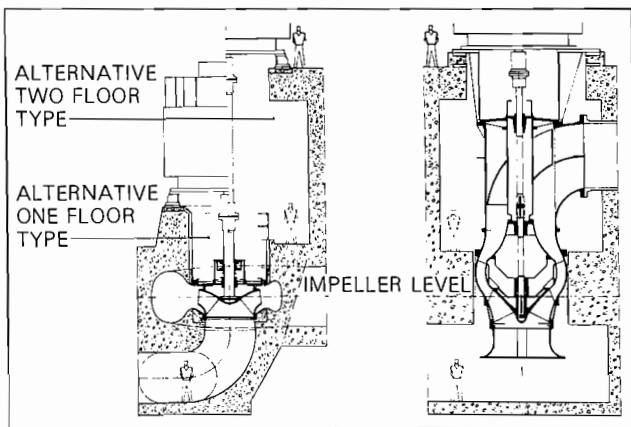


Figure 1. General Layout of a Concrete Volute Pump Compared to a Vertical Wet Pit Pump.

approximately 10 m³/s (150,000 gpm), the impeller may be examined from the suction elbow. For practically all pumps, the rotor may be observed by entering the concrete volute through a manhole.

- the rotor (impeller and shaft) can be removed quickly after dismantling the pump cover.
- the volute may be constructed by a local civil engineering company, anywhere in the world.

HYDRAULIC FEATURES

Performance Curves

Concrete volute pumps are designed for specific speeds from 3550 to 6500 (from 70 to 125 in metric system).

$$\text{Specific speed} = n Q^{1/2} H^{-3/4}$$

where

- n = rotational speed in rpm
- Q = flowrate in gpm (m³/s in metric system)
- H = total head in ft (m in metric system)

As shown in Figure 2, usual production corresponds to a flowrate range from 3 to 30 m³/s (50,000 to 500,000 gpm) and to a head range from 5 to 30 m (15 to 100 ft). It can be seen that the outlet diameter of the impeller may vary from 1 to 4 m (3 to 13 ft). In this range of duties, the concrete volute has been proven to be an economically advantageous solution.

When flowrates higher than 10 m³/s (160,000 gpm) are required, the concrete volute is always a less costly solution than the conventional vertical wet pit pump or than a welded metal volute. These high flowrates are mostly used in high power thermal and nuclear plants.

When flowrates smaller than 10 m³/s (160,000 gpm) are required, the concrete volute is still economically advantageous compared to vertical wet pit pumps or to cast metal volute pumps. Moreover, it becomes very attractive when sea or sewage water is pumped, due to the absence of corrosion and macrofouling of the casing. For these reasons, concrete volute pumps flowing between 3 and 5 m³/s (50,000 to 80,000 gpm) are used for dry-dock exhaust, draining and ballast pumps, and for sea water cooling circuits in industrial complexes (chemical, petrochemical, refinery, and steel industries). Many low flowrate concrete volute pumps have also been installed for pumping rain or sewage water, for irrigation and for drainage and flood

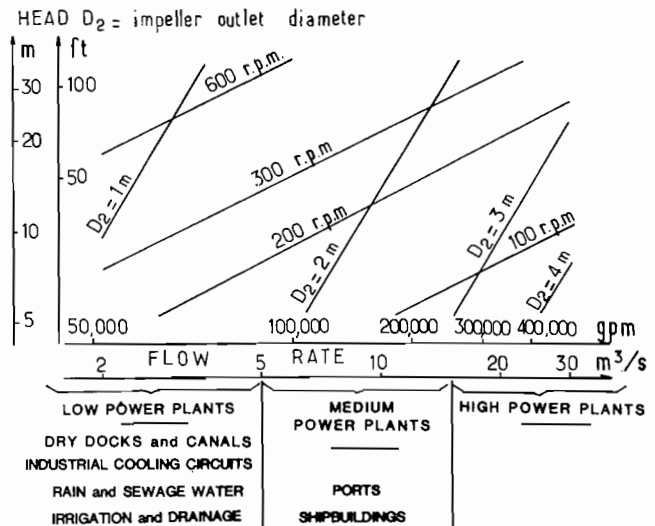


Figure 2. Usual Operating Range of Concrete Volute Pumps.

protection. When very low flowrates are required, between 2 and 3 m³/s (30,000 to 50,000 gpm), the concrete volute may still be used through the use of special formwork.

When total heads higher than 30 to 40 m (100 to 130 ft) are required, the concrete volute may still be convenient, due to provisions for avoiding flow velocities higher than 10 m/s (30 ft/s) on concrete. Total heads up to 100 m (300 ft) or even more may be considered for high flowrate storage pumps. In this case, a different technology, such as special coatings for the concrete or a grouted metal diffuser, may be used.

The impeller is of the centrifugal or mixed flow type, according to installation conditions. Lower specific speeds from 3650 to 5200 (70 to 100 in the metric system) are achieved with a centrifugal impeller. Higher specific speeds from 5200 to 6500 (100 to 125 in the metric system) are achieved with a mixed flow impeller.

Performance curves are shown in Figure 3. The main advantages shown by these curves are:

- a shut-off head no higher than approximately 1.5 times the nominal head
- a continuously negative slope for the head-flow curve
- a shut-off input power no higher than the nominal power
- a maximum overall efficiency higher than 90 percent in most cases.

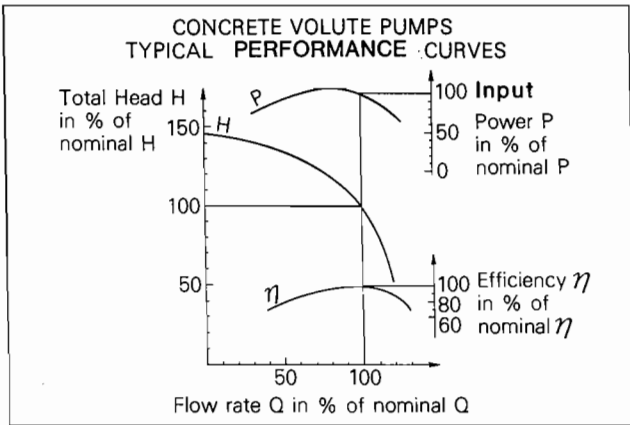


Figure 3. Typical Performance Curves.

Suction performance is shown in Figure 4. These curves correspond to a suction specific speed $S = 13,000$ ($S = 250$ in the metric system) at the nominal duty point.

$$S = n Q^{1/2} NPSH_c^{-3/4}$$

where

- n = rotational speed in rpm
- Q = flowrate in gpm (m³/s in metric system)
- $NPSH_c$ = required NPSH corresponding to 3 percent head drop

Suction performance is such that in most cases the required suction level does not need to be higher than the top of the impeller. This means in most installations that the available NPSH is equal to or slightly higher than atmospheric pressure.

The shape and submergence of the suction elbow is such that the formation of vortices and air entrainment may be more easily avoided than in a large sump where streamlines are not so well straightened.

The shape of the volute may be adapted to the available formwork technology. When an optimization of hydraulic efficiency is required, the rounded section shown in Figure 5(A) is

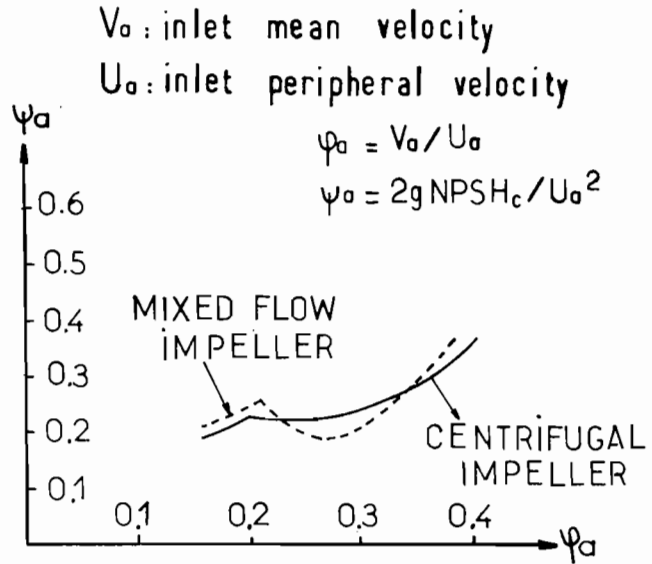


Figure 4. Suction Performance Curves.

preferred. When a simplified formwork is desired, a polygonal section may be adopted as shown in Figures 5(B) and 5(C). Such simplified shapes lead to a lower formwork cost and to easier preparation of reinforced concrete. A consequence of this simplification may be a slight drop of hydraulic efficiency. For lower specific speeds from 3650 to 5200 (70 to 100 in the metric system), the efficiency drop is never more than one percent. For higher specific speeds from 5200 to 6500 (100 to 125 in the metric system), the efficiency drop may be quite imperceptible.

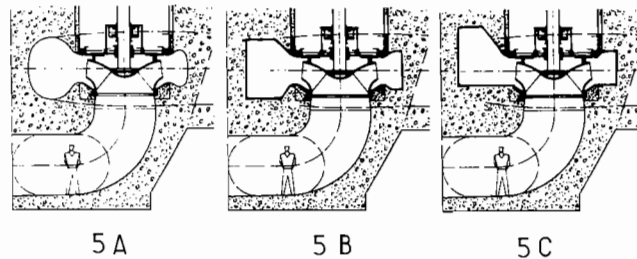


Figure 5. Different Volute Shapes.

The maximum admissible flow velocity on concrete to avoid erosion is about 10 m/s (30 ft/s). This condition is always met with total heads lower than 30 m (100 ft). In cases where a higher head leads to higher flow velocities, a special coating may be used on some parts of the internal volute area.

Internal macrofouling of the concrete volute is always avoided since the flow velocity on concrete is always higher than 3 m/s.

Adaptation to Circuit Variations

In some installations, the circuit resistance may vary to a rather large extent during normal operation. The impeller design allows continuous operation from 60 percent to 130 percent of the optimum flowrate.

In some installations, the actual circuit resistance encountered differs from specifications, and flowrate variations are not convenient for the utilities. In such conditions, it is important that the pump be adapted to the new operating point. Studies on pump models and on-site experience have shown an aptitude to adaptation as presented on Figures 6 and 7.

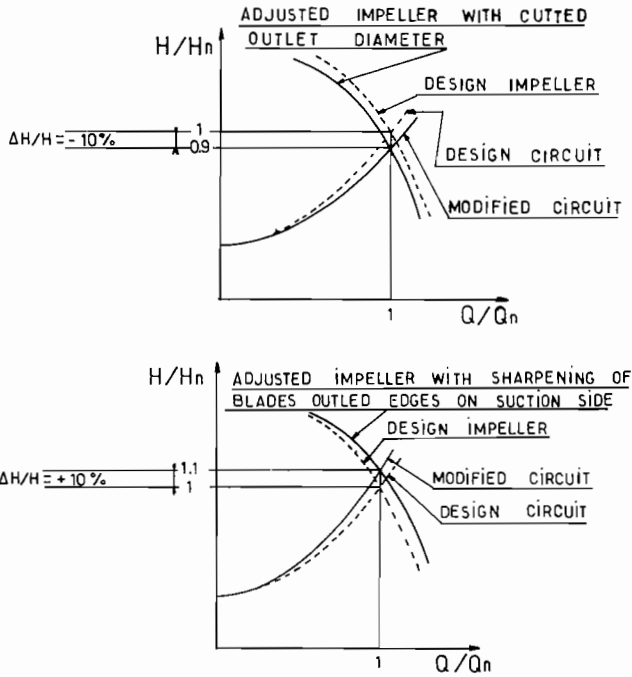


Figure 6. Examples of Adjustment of the Centrifugal Impeller of a Concrete Volute Pump for Adaptation to Circuit Resistance Variations.

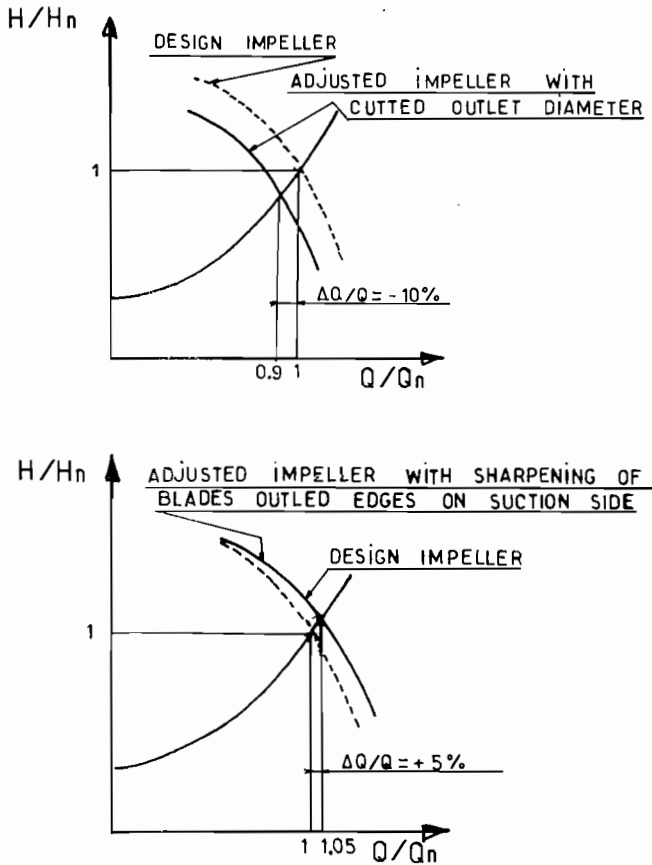


Figure 7. Examples of Adjustment of the Centrifugal Impeller of a Concrete Volute Pump to Change the Flowrate in a Given Circuit.

Hydraulic Tests: Head, Input Power, Efficiency Measurements

Hydraulic performance tests are always required to check the guaranteed requirements. Three different procedures have been developed:

Model Tests: Model tests may be easily performed in the laboratory, with respect to the intake structure, by reproducing the shape of the suction elbow. Performance curves obtained on a 360 mm (14 in) diameter model are shown on Figure 8. The model impeller was made of sand casting bronze. A movable front shroud for a better sharpening and surfacing of the blades was provided. The final blade roughness mean value is not higher than 3.2 μm (125 μin).

The model volute casing was made of cast iron with an internal surface roughness mean value of approximately 6.3 μm (250 μin). Tests have shown that for the specific speeds being considered, the volute roughness has little effect on the hydraulic efficiency.

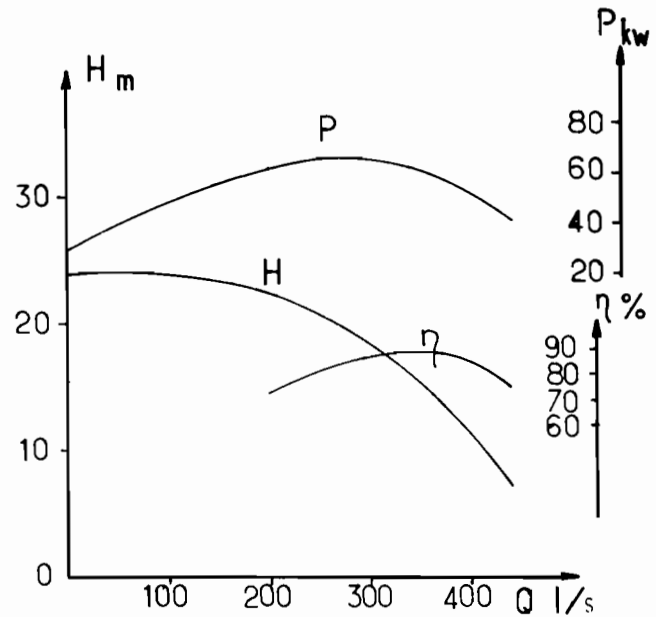


Figure 8. Model Pump Performance Curves.

Laboratory measurements allow for the accounting of the downstream pressure recovery. It has been shown that the delivery head at the volute discharge end must be calculated with a velocity head coefficient of 1.15. This means that the total outlet head may be expressed as:

$$H_2 = Z_2 + P_2/\rho g + 1.15 V_2^2/2g$$

where

- Z_2 = elevation of outlet measuring section above a reference plane
- P_2 = gauge pressure in outlet measuring section at elevation Z_2
- V_2 = mean velocity in outlet measuring section
- ρ = liquid density
- g = acceleration due to gravity.

It must also be noted that laboratory tests allow optimization of performance by fitting the impeller to the required duty. Such an operation may lead to an adequate sharpening or cutting of impeller blades as shown in Figures 6 and 7.

Acceptance model testing may be done according to the IEC P 497 international test code, using the proposed ACKERET step-up formula for efficiency [5]:

$$\Delta\eta = K (1 - \eta_M) [1 - (Re_M/Re_P)^{0.2}]$$

where

- $\Delta\eta$ = difference in hydraulic efficiency between model and prototype.
- η_M = hydraulic efficiency of the model pump.
- Re_M = Reynolds number on model pump.
- Re_P = Reynolds number on prototype pump.

Reynolds number is calculated as follows:

- $Re = D_i \sqrt{2gH}/\nu$
- D_i = pump inlet diameter (m)
- H = pump total head (m)
- g = acceleration due to gravity (ml/s²)
- ν = kinematic viscosity (m²/s)

This formula is to be applied when Re_M is higher than $5(10^6)$. The code states that a value of K between 0.4 and 0.6 can be expected from experience. Table 1 gives some examples of results from site measurements compared to model test results. In several cases the value of $K = 0.6$ seems to still be too low to find the efficiency measured on-site. For the last test of the table, the value $K = 0.5$ appears to be correct.

Site Tests. Site tests are made when sufficient straight pipe lengths are available to allow a satisfactory measurement of the flowrate. In such tests, flowrate measurement is the major problem. Two methods are commonly used: the velocity area method (with current meters) and the tracer method (with a radioactive tracer).

The velocity area method is generally applied by means of a battery of current meters installed in a section of the pipe, as shown in Figure 9. This method employs a number of individual propellers properly placed in the conduit to register the flow. The number and location of the flow meters is such as to give records at a sufficient number of individual points to permit a precise determination of the average flow in the test section. The local flow velocities are deduced from the measurement of the rotational speed of the current meters which have been previously calibrated with the same type of mounting as that used during the test. The main difficulties encountered are:

- fairly long straight lengths are required to ensure a regular velocity distribution. The gauging section must lie in a straight stretch at least 20 pipe diameters downstream and at least five pipe diameters upstream from the nearest bend.
- it is rather difficult to put current meters into operation. As a result the installation may not be available for several days.

Table 1. Comparison of Model and Test Site Results.

Rated Values On Industrial Pump			Measured Values on Model				Geometric Scale Between Model and Industrial Pump	Measured Values On Site at the Rated Total Head		Efficiency Calculated From Model Test With Ackeret Formula	
n (rpm)	H (m)	Q (m ³ /s)	n (rpm)	H (m)	Q (m ³ /s)	η	Q (m ³ /s)	η	K=0.5	K=0.6	
260	26.3	16.4	1480	21.89	0.384	0.89	6.24	16.4	0.907	—	0.903
260	22.3	16.5	1480	18.56	0.386	0.885	6.24	17.2	0.902	—	0.899
260	23.25	17.25	1480	19.35	0.404	0.885	6.24	17.2	0.905	—	0.899
260	26.6	16.4	1480	22.14	0.384	0.89	6.24	16.2	0.910	—	0.903
130	9.6	20.4	1250	12.40	0.324	0.87	8.46	20.6	0.891	0.892	—

- in the most favorable of measuring conditions, the uncertainty of the measurement of the flowrate is one to two percent.

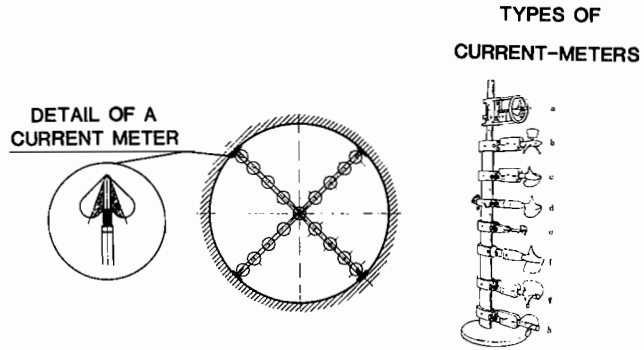


Figure 9. Battery of Stationary Current Meters on Fixed Cross-Bars in a Closed Conduit.

The tracer method is applied by measuring the transit time of a radioactive tracer injected at one point of the circuit [6]. Of course, this method is only used by specialized staff and is subject to certain safety constraints. The measurement uncertainty is approximately the same as for the current meter method (one to two percent).

Statistical Method. Test results of numerous homologous pumps have been plotted in nondimensional charts. These charts give experimental curves representing the relationships ψ (φ), Π (φ) and ψ (Π), where φ , ψ and Π are the non-dimensional flowrate, head and power, respectively. The calculation of ψ and Π from the measured head and power for a new pump allows the determination of φ from the charts without measurements of the flowrate (Figure 10).

$$\varphi = Q/\pi U_2 D_2 b_2$$

$$\psi = 2gH / U_2^2$$

$$\Pi = 2P / \pi\rho U_2^3 D_2 b_2$$

where

- Q = flowrate (m³/s)
- H = total head (m)
- P = input power (W)
- D_2 = impeller outlet diameter (m)
- b_2 = impeller outlet width (m)
- U_2 = impeller outlet peripheral velocity (m/s)
- ρ = density (kg/m³)

g = acceleration due to gravity (m/s^2)
 π = pi (3.1416)

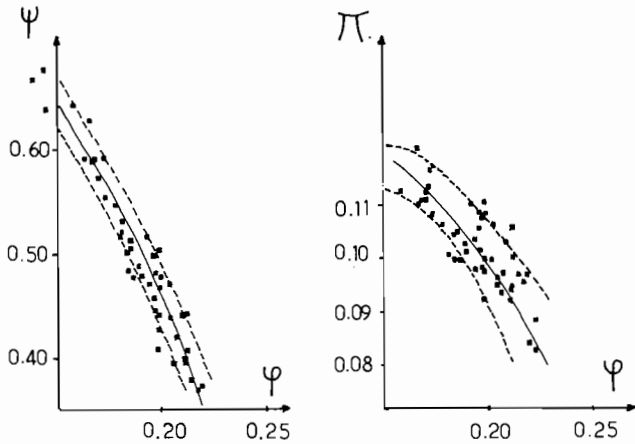


Figure 10. Non-Dimensional Charts from Site Test Results.

Cavitation Tests

It must be noted that laboratory tests allow visualization of the cavitation development at the impeller inlet (Figure 11). Cavitation tests have led to the determination of the best blade inlet edge shape in order to optimize the “no bubble” required NPSH. Cavitation tests on the model are made using the same value of the Thoma coefficient $\sigma = NPSH/H$ as the industrial pump will produce. This means approximately the same value of available NPSH will be produced, since model tests are made with a total head not much different from the full size pump.



Figure 11. Cavitation at the Impeller Inlet.

MECHANICAL FEATURES

The very simple mechanical design is the major advantage of concrete volute pumps. Some of the features that give the concrete volute pump the highest reliability are shown in Figures 12 and 13, and include short shafts, a conventional bearing and a simple seal.

The shaft is usually very short, which means no vibration problems and no sensitive axial length variations. The shaft is never in contact with water, since the shorter part located under the casing cover is protected by a shaft sleeve and the longer upper part is in the air. This explains why no corrosion problems have been encountered. When fresh water is pumped, the shaft is made of AF 50 S forged carbon steel (similar to AISI 1045) and the protective sleeve is made of cast iron. When saline water is pumped, the shaft is made of Z20 C13 forged stainless steel (AISI 420) and the protection sleeve is constructed of stainless steel or aluminum brass alloy.

The bearing is an oil lubricated journal bearing, which means no wear, easy inspection and simplified maintenance. Lubrication is assured by the rotation of an oil box, driven by the shaft. This independent lubrication system allows start-up and running of the pump without any external device. The design of the bearing has many times even proved to be reliable enough to operate in water during occasional flooding of the pumping house.

The thrust bearing is a very conventional tilting pad type. It may be equally located above the pump cover, in the motor or in the gear box, if any. It is designed for a maximum axial thrust of about 100,000 daN.

The shaft seal is usually a gland packing. The cooling liquid may be delivered from a tap on the discharge pipe, even in the case of sea water. If solid particles in the pumped water are not too large, the packing may operate satisfactorily even in the case of a cooling liquid shortage. When large solid particles are present in water ($> 100 \mu m$), the cooling liquid may have to be circulated through a cyclone. Normal operating conditions have proved to lead to no excessive or damageable wear of the shaft sleeve after several years of operation.

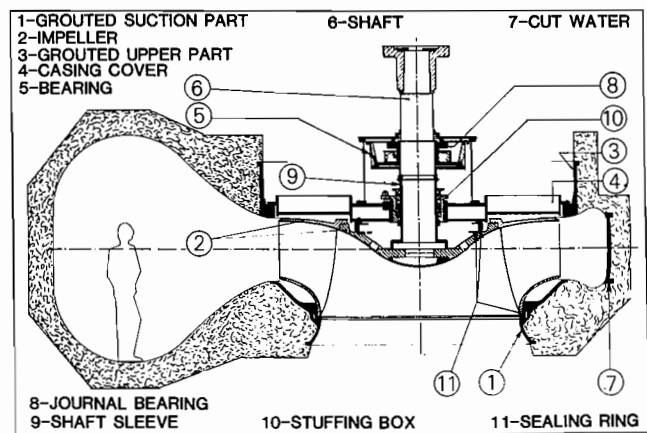


Figure 12. Concrete Volute Pump Cross-Section.

MAINTENANCE

The principle of the concrete volute leads to low operational costs because of reduced maintenance and easy inspection. The only operating instructions are in the remote control of the bearing oil level and temperature.

The main inspections for maintenance are as follows:

- a yearly preventive maintenance to check the quality of lubrication oil (no stopping of the pump is required) and the gland packing. The packing may be replaced without dewater-

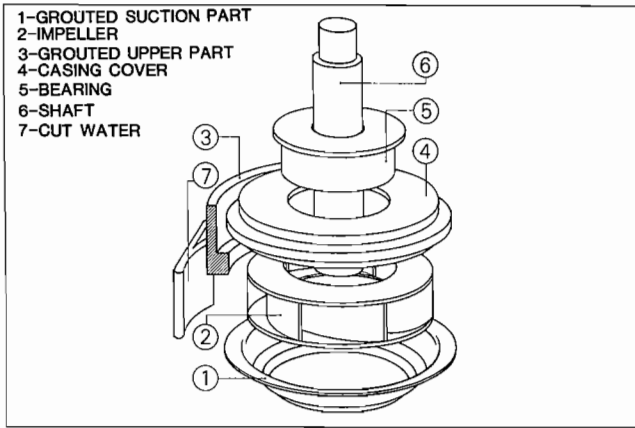


Figure 13. Concrete Volute Pump: Main Mechanical Parts.

ing the pump. When high resistance packing is used, the replacement may be required only after several years of service.

- every five years it is recommended that the bearing clearance be checked. The bearing cap may be removed without other dismantling.
- the wear ring clearances may be checked by dewatering the pump. No dismantling is necessary,
- most pumps of this type can stay in operation for five to seven years (50,000 hours) with no replacement of major parts (bearing, shaft sleeve, wear rings). When these parts have to be replaced, they can be removed very quickly because of the pull-out construction of this pump.

ECONOMICAL EVALUATION

The economical advantage of the concrete volute pump is made clear with the following examples:

- The general layout of two different solutions corresponding to a flowrate of 14 m³/s (220,000 gpm) and a total head of 20 m (65.6 ft) with a rotational speed of 200 rpm is shown in Figure 1. The study of this installation has led to the following conclusions: 1) The civil work, in the case of the vertical wet pit pump, is about 20 percent more expensive, because the walls and the bases have to be strongly reinforced to hold up the much greater weight of the vertical pump in vibration free conditions. 2) The weight of mechanical parts in the case of the vertical wet pit pump is more than twice the weight of the

mechanical parts in the concrete volute pump (70 tons compared to 30 tons).

- The general layout of two different solutions to the installation of cooling water pumps in a power plant is given in Figure 14. The power plant consisted of eight units of 300 MW each, with a cooling water flowrate per unit of 11.7 m³/s (184,000 gpm) and a total head of 17 m (56 ft). In one solution, two 50 percent capacity vertical pumps per unit are installed, for a total of 16 vertical pumps. In the other solution, one 100 percent capacity concrete volute pump is installed for each of the eight units. This last solution corresponds to the current practice in Europe, due to the high reliability of the concrete volute pump.

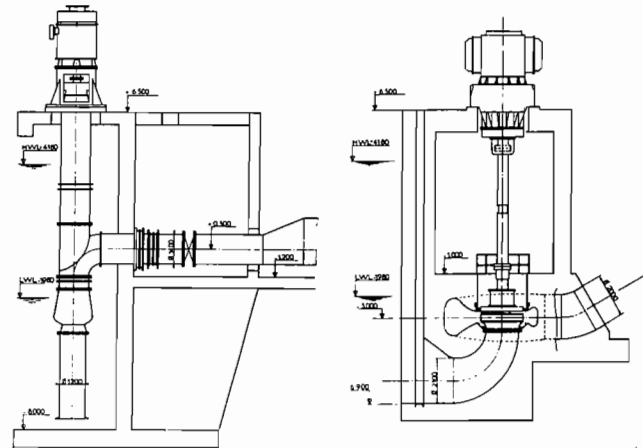


Figure 14. Comparison of Two Different Solutions for a Cooling Water Pump Project.

A very precise study of civil work and mechanical equipment has led to the data presented in Tables 2 and 3. The higher cost of civil work in the case of the vertical wet pit pumps is due to:

- stronger walls and bases to hold up a higher mass in vibration free conditions
- the need of a valve chamber
- a wider and longer pumping station (10.75 m x 73 m as opposed to 8 m x 51 m)

Table 2. Cost Comparison of Civil Works.

Type of Solution			Solution 1 Two Vertical Pumps 5.85 m ³ /s (92,000 gpm)		Solution 2 One Concrete Volute Pump 11.7 m ³ /s (184,000 gpm)		Difference
Description	Unit	Unit Price	Quantity	Amounts	Quantity	Amounts	
		US \$		US \$		US \$	
Surfacing concrete	C.Y.	63	92	5,976	72	4,536	
Reinforced concrete	C.Y.	70	5,620	393,400	4,250	297,500	
Reinforcement	T	704	242	170,368	152	107,008	
Vertical formworks	S.Ft	2	96,460	192,920	28,290	56,580	
Horizontal formworks	S.Ft	3	12,185	36,555	2,920	8,760	
Circular and conic formworks	S.Ft	5	-	-	6,300	31,500	
Volute formworks	S.Ft		10	-	3,390	33,900	
Estimation US \$				799,039		539,784	259,255

Table 3. Cost Comparison of Pumping Systems.

Type of Solution	Solution 1	Solution 2	Difference
	2 Vertical Pumps	1 Concrete Volute Pump	
	US \$	US \$	US \$
Civil works	799,039	539,784	-259,255
Pumping Equipment	1,148,890	753,039	-395,851
Total (US \$)	1,947,929	1,292,823	-655,106
	%	100	66
			-34

- a larger mass of formwork (109,000 s ft against 31,000 s ft)

The higher cost of mechanical equipment is due to the much greater weight of mechanical parts in the case of vertical wet pit pumps. Therefore, for this particular project, the overall cost of pumping systems was found to be 34 percent lower for concrete volute pumps.

CONCLUSION

The main technical features presented here may explain why concrete volute pumps have been used extensively, for many years, in several countries. Their high reliability make them most convenient for many fields, such as power plants, dry docks, drainage, irrigation, etc.

Their easy design and maintenance make concrete volute pumps particularly convenient to be installed in countries where maximum local fabrication and minimum maintenance are required. The principal technical advantages are indicated in Table 4.

Moreover, the use of concrete volute pumps may lead to very important savings by lowering the investment cost of the pumping system.

Type	CONCRETE VOLUTE PUMP	VERTICAL METAL CASING PUMP
	DRY-PIT	WET-PIT
INTAKE	Hydraulic design : no dead water area, no vortices, no micro/macro-fouling, no deposit, stream lined flow pattern	Sump or Pit : dead water area, chance of vortices, micro/macro-fouling, sand or silt deposit, irregular flow pattern
BEARING	Out of water : no wear, oil lubricated, easy temperature check, minimum 10 years life, simplified maintenance	Submerged bearing bushes : possible setbacks, less reliability, difficult-expensive to maintain
SHAFT	Dry, no water contact, no corrosion, long life, no vibrations	In water, submitted to irregular stresses and problems, possible vibrations and cracks
CASING	No corrosion, no erosion, no fouling, no vibrations, no maintenance at all	Corrosion (chemical and electrolytic), external fouling, vibrations, cracks, difficult-heavy to maintain
INSPECTION MAINTENANCE	Simple and easy, no heavy loads, inspections without dismantling, general overhaul at intervals of 5 to 7 years	Long duration and costly interventions, heavy loads, requires general overhaul, general overhaul at intervals of 2 or 3 years (often less)

Table 4. Technical Comparison of Concrete Volute Pump and Conventional Vertical Wet Pit Pump.

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