Introduction to the Pumps, Valves and Seals Review

DOWNSTREAM PUMP DEVELOPMENTS

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discuss the advancements in centrifugal pumps technology for the downstream oil and gas industry.

The downstream oil and gas industry is approaching its first century. Developed in the US at the beginning of the 1900s, today the refining and gas processing industry has gigantic dimensions and a high degree of technological sophistication.

Rotating machinery technology plays an important role in the downstream industry. In fact, plant process conditions may be severe: a normal sized topping unit may provide output capability of 1500 tph and in critical process points, such as for furnace charge pumps, temperatures are close to 800˚C, requiring specialised technological solutions. A fluid catalytic cracking (FCC) plant requires the feed to be mixed with the catalyst and then pumped to the reactor, with temperatures of approximately 500˚C. Air required by the process is typically supplied with centrifugal or axial compressors with normal flow of approximately 50 000 Nm^3/hr; power can also reach several megawatts. Rotating machinery for compression and pumping applications often plays a critical role in determining the overall robustness of a plant. Within this equipment category, centrifugal pumps, being present in almost all plant processes, are of crucial importance.

REGULATIONS AND INDUSTRY STANDARDS

The centrifugal pump market covers downstream process applications with a wide range of sizes. Many centrifugal pump configurations have been developed for different applications, from single to multistage, axial or radial split, horizontal or vertical rotor position.

By far the most common is the horizontal pump type, used in a wide range of pressures (up to 400 bars) and temperatures (up to 450˚C). Meanwhile, vertical pumps are used for a more restricted range of applications, predominantly in low NPSHa conditions and very low temperatures.

Many large manufacturers populate the centrifugal pumps industry (Tables 1 and 2). Technical regulations and industry standards, even today, are primary actors in this scenario. For process industry pumps, API 610 and

Table 1. Market research and analysis results

	Ebara	Flowserve	Sulzer	KSB	Shin Nippon	Ruhrpumpen
Annual sales	€3671 million	€3479 million	€3280 million	€2268 million	€153 million	€66 million
Compressors	✓					
Steam turbine	✓				✓	
Hydraulic decoking systems		✓				✓
High energy barrel pumps		✓	✓	✓		
High energy pipeline pumps		✓	✓		✓	
Cryogenic pumps and expanders	✓	✓	✓	✓		✓
API process pump	✓	✓	✓	✓	✓	✓
Vertical can pumps	✓	✓	✓	✓	✓	✓
Vertical sump pumps	✓	✓	✓	✓	✓	✓
Vertical mixed flow pumps	✓	✓	✓	✓	✓	✓
Non-API between bearings	✓	✓	✓	✓		
Chemical process pumps		✓		✓		
Vertical deepwell submersible		✓				
Rotary pumps		✓				
Seals and seals systems		✓				

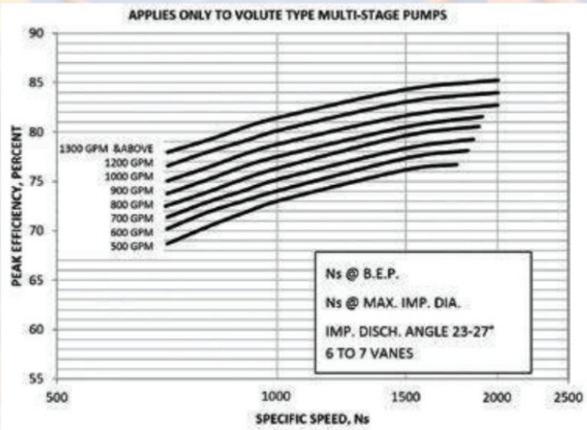

Figure 1. Lobanoff Ross graph.

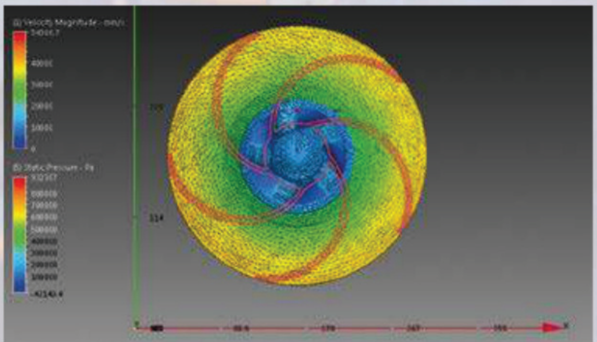

Figure 2. Pressure contours: velocity vectors in impeller.

Hydraulic Institute codes provide wide and comprehensive guidelines that drive the whole pump production process. Developed by a board of manufacturers and customers, these standards cover key aspects from early engineering to manufacturing. The API 610 standards have been subject to revisions over time: criteria for evaluating pump efficiency moved from previous tolerances on the efficiency to actual tolerances imposed on the overall adsorbed power. Vibration limits also had analogous modifications, reflecting the increasing focus of pumps customers and manufacturers to obtain longer machine lifecycles and improved energy efficiency.

TECHNOLOGICAL DEVELOPMENTS

Operators' continuous search for final market competitiveness pushed centrifugal pump technology development both in terms of performance requirements and overall cost reduction. This article will provide a brief overview of some of these technological improvements.

Metallic material technology

The evolution of metallic material technology is a notable development. As already acknowledged, pumps are subject to corrosion, erosion and fatigue during operation. From a design point of view, appropriate material selection is a primary task for a satisfactory machine lifetime. First developed in the 1950s, today material technology has resulted in better materials resistance to the aforementioned phenomena. Actual metallurgical processes have higher control over the chemistry of materials, as in the case of duplex steels (CD4MCu) or special steel grades such as precipitation hardening 17-4-PH, often used for shafts. In other cases, innovative processes such as plasma or laser coatings for sleeve surface hardening result in better wear resistance. Development of computer FEM methods has also resulted in a better understanding of the stress field inside pump components.

The continuous push for better performance and higher operative speeds provided a boost to the pump

Table 2. Market research and analysis results

Performance	Ruhrpumpen	Flowserve	Sulzer	Shin Nippon	KSB	Ebara
Volumetric flow rate Q (m^3/hr)	10 ÷ 31 800	27 ÷ 15 000	60 ÷ 5000	500 ÷ 9000	190 ÷ 3600	90 ÷ 5500
Polytropic head H (m)	10 ÷ 4572	85 ÷ 900	250 ÷ 450	150 ÷ 2200	77 ÷ 5300	140 ÷ 3000
Temperature T (°C)	-120 ÷ 450	-160 ÷ 450	-75 ÷ 425	-120 ÷ 1500	100 ÷ 300	-105 ÷ 2200
Discharge pressure PM (bar)	11 ÷ 90	25 ÷ 650	50 ÷ 100	40 ÷ 100	16 ÷ 560	15.7 ÷ 235
Speed n 50/60 Hz (rpm)	Until 3560	Until 13 000	Until 3600	Until 6000	From 2900 Until 6750	Until 8400

rotor dynamic research field. In addition, the availability of computational techniques and adequate computational powers has been an important factor.

Modern rotating machinery design takes advantage of experiences and the availability of dedicated software tools, which allows for accurate evaluations in a number of mechanical design points, such as the bearing selection, balancing pistons and sleeve clearances sizing. All these elements, along with the boundary design operative conditions, contribute to the final stability of the rotor.

Cavitation

Another well known problem that affects centrifugal pumps is cavitation. It develops during fluid vapourisation, where the net pressure becomes lower than the vapour pressure. Downstream pressure recovery causes the sudden implosion of vapour bubbles and pitting, usually on the impeller. Cavitation effects may be dramatic, ranging from performance degradation to complete failure.

In the past, expert pump operators used to detect cavitation by recognising the characteristic rubble noise. Recent advances in vibration studies show that incoming cavitation can also be detected from harmonics (FFT), opening the door to automated diagnostics. The traditional approach to this problem is based on plant sizing with a static safety margin to NPSHr (from OEM) in the operative point. Correct cavitation monitoring is achievable by measuring pressure, temperature and fluid speed at the nearest machine suction point. Nevertheless, permanently installed monitoring systems were used in the past in a very limited number of cases, as the cost of monitoring systems was deemed excessive, especially for small machines. The arrival of affordable logic controllers to the market has changed this scenario, and today even small centrifugal pumps may benefit from these control and monitoring systems.

Testing methods

Another element that has consistently contributed to pump technology improvement is the development of testing methods. The commercial availability of advanced vibration measurement systems has allowed for the acquisition of a considerable amount of data. Proximity probes and body velocity transducers enable testing engineers to execute detailed investigations on machinery vibratory behaviour and correlations between mechanical parameters, flow readings, performance, FFT spectrum harmonic components and orbit shapes, and the upset of specific phenomena such as cavitation or internal flow rotating stalls.

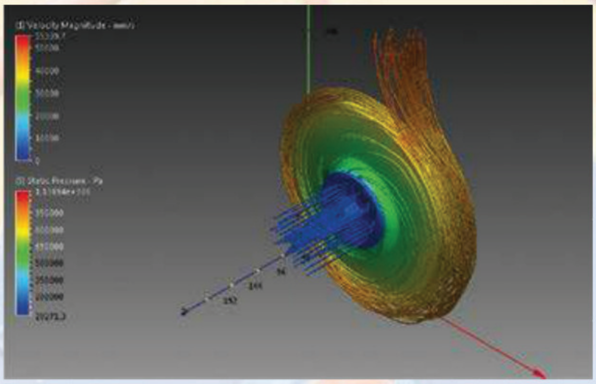

Figure 3. Pressure contours and streamlines.

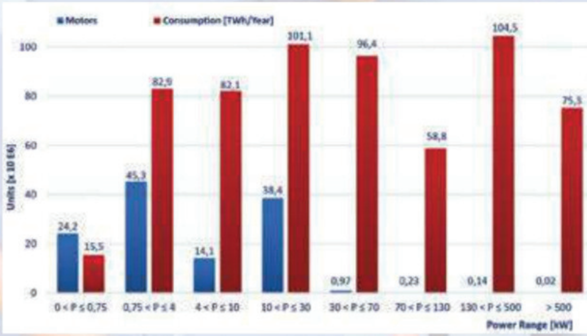

Figure 4. Motors and relative power consumption.

Computational fluid dynamics

The introduction of computational fluid dynamics (CFD) also influenced the development of the process pump industry. The hydraulic design of pump flow patterns using 3D shapes is in fact a delicate task. Increasing computational power and the availability of reliable codes resulted in consistent improvements to the centrifugal pump design process and the integration of original equipment manufacturer (OEM) experience with reliable simulation predictions. Modern CFD commercial codes have advanced capabilities for modelling viscid and inviscid fluids, and offer several turbulence equations and non-stationary algorithms for turbomachinery rotating regions. The overall design loop needs to be closed, with final physical machine testing at the OEM's workshop; however, the implementation of CFD methods provides better designs in shorter turnaround times. The computer simulation allows operators to develop hydraulic channel shapes optimised for specific goals (i.e. max efficiency,

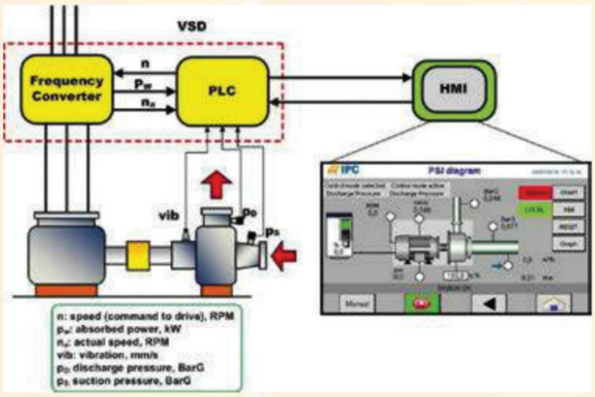

Figure 5. Proteo architecture.

NPSHr) in a shorter timeframe, using the operative conditions specified by the customer. The importance of these advancements became even more evident when considering the possibility to manufacture customised hydraulic parts obtained from CFD design by integration with modern computer aided design (CAD)/computer aided manufacturing (CAM) technology.

Control system advancements

The improvement of control systems is another important development area for pump technology. As mentioned above, centrifugal pumps are widely used in the oil and gas industry. Data relative to the European community shows that the greatest part of adsorbed energy comes from pump drive applications (medium low power range up to almost the totality of driver installed power), which absorb approximately 76% of overall energy.

Despite this considerable importance, the idea of a control system for low power pump ranges has received little attention during the past few decades when compared to larger size pumps, where advanced control systems are commonly used. This is mainly down to the low ratio benefits/costs for small size pumps, due to the high impact that a control system would have on overall pumping station costs.

One approach was to provide the installation with multiple spare items. This kind of redundancy based approach requires higher initial installation costs for multiple pumps and shifts cost appearance to the operation phase where, in many cases, pumps operate until the end of their lifecycle. In this case, the connected economical impacts are not accounted for in the preliminary plant design stage, but become apparent during operation.

Today the installation of dedicated control systems may be advantadgeous even for low power/small size pumps. Considerable energy savings are made possible through the integration of variable frequency drive (VFD) systems, and additional operational and maintenance savings (extension of uptimes and ultimate machine life) are achievable by using advanced auto diagnostic control systems.

Modern pump control systems, such as the IPC PROTEO, implement the idea of complete pump automation using a minimal number of installed field sensors. This goal is achievable through the application of performance based models (PBM), made possible due to the increased computational capability of commercial programmable logic controller (PLC) systems. These systems provide capabilities that are used to assist the machine control tasks, as well as for protection and auto diagnostic purposes. Compared to an unmonitored installation case, slightly higher installation costs would be offset by reduced maintenance costs, repair costs and production downtimes in the future.

The main characteristics and advantages of these systems include:

- Multivariable control capability: The user sets the process parameter to be controlled, the system provides continuous monitoring of all relevant process parameters and automatically shifts the control over the parameter that requires protection intervention.
- VFD drive: When compared to traditional throttling methods, this allows for large power adsorption reduction, and consequent higher energy efficiency (up to 40%, depending on specific conditions).
- PBM: The availability of the machine model allows it to predict the expected performance in actual operative conditions. Field measurement allows the operator to determine the actual performance. Comparison/deviation of the expected performance to actual performance enables the system to provide auto diagnostic indications (particular anomalies such as cavitation upset, mechanical degradation, transmitters failure, etc.) and activate correlated protection actions.

CONCLUSION

Many of these pump technology trends are in a continuous state of evolution, and recent technological advancements are expected to benefit both users and manufacturers. As mentioned above, CFD is a very interesting area of development. CFD and CAD/CAM integration is under examination at IPC, where a new high efficiency pump design is being developed. It is expected that the adoption of these methods will increase the possibility of developing an optimised custom design for each specific pump case.

When compared to traditional pump selection methods, based on catalogue selection procedures, this custom design process would allow operators to better reach the design operating point, improve efficiency and achieve all of the associated benefits. In conjunction with these advancements, on the hydraulic side it is expected that the diffusion of new control systems using PBM and the implementation of auto diagnostic software algorithms, such as PROTEO, will also allow users to achieve these additional benefits. Integration of VFD for improved operational power management within control system embedding performance based models will result in energy savings, a reduction in maintenance costs and maximisation of uptimes. The integration of all of these methods is understood as a key element for the successful operation of next generation centrifugal pumps.