

## Fluids Engineering in the Pump Industry

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**Introduction.** In speaking of fluids engineering, one is often likely to be dealing with pumps. Pumps are at least as ubiquitous worldwide as electric motors. As they are primarily concerned with moving and pressurizing liquids, they are the premier fluid machine. They come in the hydrostatic (reciprocating and rotary positive displacement) and the rotodynamic (centrifugal and axial flow) configurations. They have been the focus of mechanical engineers and the ASME in particular throughout the past century. In the first half of the century, this focus was facilitated by the ASME Hydraulic Division, which had a “Pumping Machinery Committee.” Later, the work of this committee was combined with that of others in a “Fluid Machinery Committee.” Today, the “Fluid Applications and Systems Technical Committee of the Fluids Engineering Division” continues to sponsor technical publications and meetings in the area of fluid machinery and pumps in particular.

**Pumps in the Transactions of the ASME in the 20<sup>th</sup> Century.** In an early example, the *Transactions of the ASME* from the year 1905 had an article by Wm. O. Webber in which he says, “great improvements have been made in centrifugal pumping in the last decade,” and he goes on to illustrate new multistage pumps conceived and built by B. Jackson and others. As mechanical engineers learned about these machines, they shared their developing knowledge and experience within the ASME meetings and publications infrastructure. It was a matter of professional necessity to have these associations. The *Transactions* throughout the century contain a procession of articles in which the mechanical and hydraulic phenomena are successively analyzed and understood, the level of complexity increasing as one mystery after another was solved. For example, as early as 1929, the *Transactions* carried an article by J. P. Den Hartog that shed considerable light on the vexing problem of pressure pulsations in large hydraulic turbines and pumps. A related example is the landmark research on both design and off-design flows in impellers that was reported by Fischer and Thoma in the 1932 *Transactions*, providing further understanding of the origin and nature of pressure

pulsations and the accompanying vibratory, structural, mechanical response.

Application of the knowledge and experience up to that time was ably illustrated by Carl Blom, an accomplished pump engineer who wrote in the 1950 *Transactions* about the very large irrigation pumps he designed for the Grand Coulee project. Problems with large pumps of this kind became the concern of highly productive researchers like R. T. Knapp, who in 1955 reported on the dependence of cavitation erosion on liquid velocity. And, since the developed head of a centrifugal pump varies as the square of the fluid velocity in the machine, this in turn led to an understanding of why higher-energy pumps are more likely to suffer from this damaging phenomenon. Further insight was then revealed by H. Stahl and A. J. Stepanoff in the 1956 *Transactions* in which they demonstrated how the thermodynamic vaporization properties of the pumped liquid could lead to a reduction of cavitation activity at high temperatures at the same “NPSH” (or liquid pressure head in excess of the vapor pressure). Transaction articles on this subject followed. C. E. Brennen (1994) then showed how cavitation can cause profound instabilities in pump and inducer operation. In the latter decades of the century, he and his students produced a succession of papers that defined the sometimes obscure fluid phenomena that can produce mechanical instability in rotodynamic pumps. Other academics such as A. J. Acosta and engineers such as I. J. Karassik became names that are synonymous with all types of rotodynamic pumps. Such machines have been applied to the preponderance of pumping duties from water transport, including potable water supply, utility boiler feedwater, and sewage applications; use in chemical and petroleum processes, including the massive movement of crude oil; to liquid rocket propellant pumps.

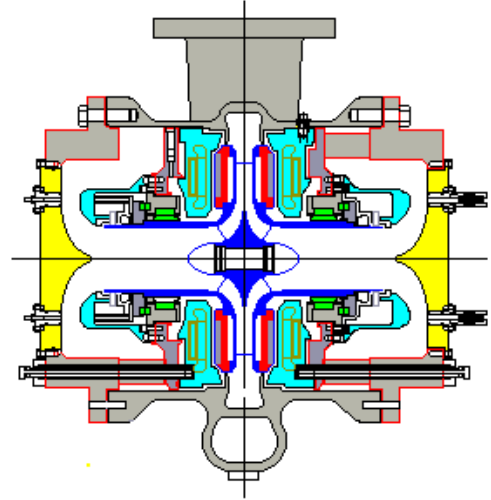
**Positive Displacement Pumps.** The design of positive displacement pumps also benefited from some of this knowledge, the mechanical design often commanding as much if not most of the engineering design attention. This includes rotary positive displacement machines such as screw pumps, which were originally used to pump highly

viscous fluids that could not be handled by rotodynamic pumps. The ability of such machines to deliver a relatively fixed volume rate (at intake) of fluid against any discharge pressure level has led to increasing application of such rotary positive displacement pumps to fluids of lower viscosity – and in the past decade to mixtures of liquid and gas seen mainly in petroleum production.

**Drivers of Pump Developments.** By the end of the century, observers pointed out that these technical achievements had in reality been driven by social developments and pressures. Following are the driving forces that have undergirded pump development

1. *The Industrial Revolution.* Up until WWII, the technical developments and growth in production of the pump industry had been fueled by the massive demands of the industrial revolution that built our modern society.
2. *Post WWII Expansion.* Further expansion of the industry and the product mix occurred for a few decades after WWII, as H. Ohashi and Y. Tsujimoto (1997) pointed out, in order to satisfy the pent-up demand that had gone unfulfilled in the war years. It was during this period that some of the greatest technical advances of the century were made, enabling the industry to produce larger pumps of greater power density, the most spectacular machines in this respect being the liquid rocket turbopumps. This effort was concluded by addressing the need for greater reliability and durability of commercial pumps. Here, the emphasis was on large, multistage electric utility boiler feedwater pumps and oil-field injection and pipeline pumps.
3. *The Environmental Challenge.* Ohashi and Tsujimoto observed that environmental concerns then became the driver, curbing emissions being the paramount concern. This influence has led to better sealing of pumps, including sealless, magnetically coupled chemical pumps. The ultimate product in this regard could be the “integral motor pump.” Here, the impeller shrouds also serve as the rotor of the motor that drives it; (see Figure 1.) Karassik has written articles on this concept; which is now being developed by Sloteman and Piercy (2000)
4. *Globalization.* Today, the environmental influence on the pump industry still exists; although, it is being overshadowed today by massive globalization and consolidation of the

industry. In this latest situation, the fluids engineering and other technical challenges are assumed to be solvable by the emerging billion-dollar-plus multinational pump companies, who now emphasize quality, productivity, and faster delivery as they battle for global market share.



**Fig 1. Integration of a 400 hp double-suction pump with a permanent magnet motor.**

**Engineering Requirements for Future Success in the Pump Industry.** While this globalization apparently de-emphasizes the technical and fluids engineering aspects that have always characterized the pump industry, technical improvements will continue to be necessary to maintain global competitiveness. As we learned from the automobile industry with regard to internal combustion engines, the apparently mature pump product has a lot of room for improvement. In the light of past and more recent technical achievements, we can get an idea of the emerging role of mechanical engineering, fluids engineering included, in this new and challenging industrial environment. Here then are the areas of expertise that must be continuously improved if success is to be achieved in the new globalized pump industry:

- In a 1996 *ASME Transactions (JFE)* article, P. Cooper cites among other things the successes that can be expected in *stabilizing the head characteristic* of large, high-specific-speed mixed-flow pumps. Computational Fluid Dynamics (CFD) is mentioned as a tool to aid in making such improvements.
- CFD also promises to take the guesswork out of predicting the pump *performance curves*. Missing the performance on a new design has

been a costly element of the pump business for a long time.

- Eliminating *vibrations and off-design pressure and flow fluctuations* is another challenge that still remains, and superior performance in these areas will influence the choice of pumping equipment by customers. In a companion article to that of Ohashi and Tsujimoto (1997), S. Gopalakrishnan emphasizes the advances that have been made in finding solutions to both rotor- and structure-related vibrations.
- Gopalakrishnan also discusses the fact that *structural modal analysis* – both finite-element (FEA) and experimental – have become both common and essential as an aid to the design and improvement of the pump components and mounting configurations.
- Another area that will continue to be technically challenging was discussed by Cooper (1996) is *cavitation*. This is a phenomenon that affects both performance and pump life. In the future, users will routinely impose a life requirement of, e.g., five or more years against failure of pump parts from cavitation erosion. Cavitation is now routinely observed in the laboratory (Figure 2), and this has led to improved blade shapes that have reduced and even eliminated cavitation damage in some important applications. Together with related improvements in materials, this is a major reason for the extended pump life that was achieved in commercial pumps as mentioned earlier in this article.

**Conclusion.** Even though the pump industry is challenged globally and must continuously improve productivity, quality, and service to the customer to stay in business; success will also depend on a brain trust of technical people in the organization, each of whom maintain and continuously evolve and creatively apply superior technical capability as a key element of the company's business strategy. The temptation to economize in the critical fluids engineering areas of flow stability, cavitation, performance prediction, as well as the mechanical analysis areas surrounding vibratory behavior and the area of materials technology will open the way for a global competitor to supersede whole product lines with superior performance, reliability and durability. As has been proven globally in the automobile industry, for example; a company cannot survive without continuous technical improvement and the creation of new product lines containing such improvements. What seem today

to be stable product lines with an indefinite future stand a good chance of being superseded and phased out. Good business planning therefore must include the engineering expertise that has made such business possible in the past and will without doubt continue to do so in the future.



**Fig. 2 Viewing cavitation activity in a model pipeline pump impeller.**

### References

- Blom, C., 1950, "Developments of the Hydraulic Design for the Grand Coulee Pumps," *Trans. ASME*, Jan., pp. 53-70.
- Brennen, C. E., 1994, *Hydrodynamics of Pumps*, Concepts ETI and Oxford University Press.
- Cooper, P., 1996, "Perspective: The New Face of R&D—A Case Study of the Pump Industry," *Trans. ASME*, Vol 118, December, pp. 654-664.
- Den Hartog, J. P., 1929, "Mechanical Vibrations in Penstocks of Hydraulic Turbine Installations," *Trans. ASME*, HYD-51-13.
- Fischer, K., and Thoma, D., 1932, "Investigation of the Flow Conditions in a Centrifugal Pump," *Trans. ASME*, Vol. 54, pp. 143-155.
- Knapp, R. T., 1955, "Recent Investigations of the Mechanics of Cavitation and Cavitation Damage," *Trans. ASME*, October, pp. 1045-1054.
- Ohashi, H. and Tsujimoto, Y.; Hergt, P.; and Gopalakrishnan, S., 1997, "Pump Research and Development – Past, Present and Future," three papers on the Japanese, European, and American Perspectives respectively; 1997 ASME Fluids Engineering Division Summer Meeting, (available on CD from ASME.)
- Sloteman, D. P.; and Piercy, M., 2000, "Developing Sealless Integral Motor Pumps Using Axial Field, Permanent Magnet, Disk Motors," *Proceedings of the Seventeenth International Pump Users Symposium*, Texas A&M University, pp. 53-67.
- Stahl, H. A., and Stepanoff, A. J., 1956, "Thermodynamic Aspects of Cavitation in Centrifugal Pumps," *Trans. ASME*, Vol. 78, pp. 1691-1693.
- Webber, Wm. O., 1905, "Some Types of Centrifugal Pumps," *Trans. ASME*, Vol XXVI, pp. 764-800.