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Applications of Multipath Ultrasonic Flowmeters: Hot-Tapping and Rectangular, Tapered Conduits

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Summary

Several four-path acoustic transit time flowmeters were installed while the hydro power plant was still in operation; generating revenue from the power produced. Requiring no down-time, hot-tapping was applied on five steel penstocks in Oregon, USA. For this purpose the new "drill and tap" hot-tapping machine and procedure was designed for penstocks with head pressures up to 35 bar (500 psi). The "drill and tap" hot-tapping design, procedure and application according to IEC 41 or ASME PTC 18-1992 standard will be presented. The second part introduces to a further interesting application of multipah ultrasonic flowmeters at the Aswan High Dam in Egypt. Two eight-path acoustic transit time flowmeters are going to be installed in a rectangular and tapered conduits. A brief introduction is given on the application.

Introduction

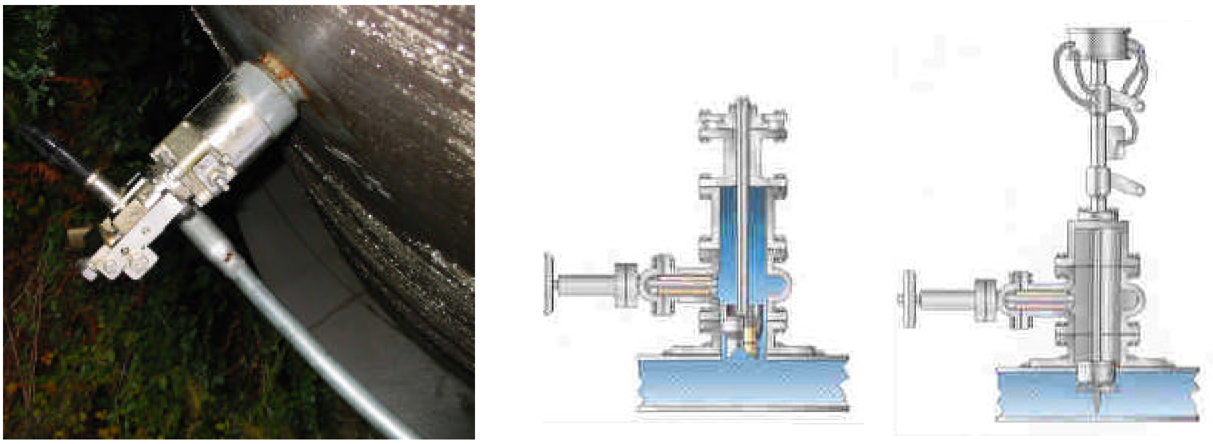
Flow is one of the most important physical parameter to be measured in the industry and water management. There are various kinds of flowmeters available depending on the requirements defined by the different market segments. Transit time differential method is today's state-of-the-art technology and the most widely used principle. The first acoustic instrument goes back to 1928 when RUETTEN, for the first time, measured velocities in liquid by means of ultrasound (ETT). In 1955, the US-based company Fischer & Porter offered the first commercially available Ultrasonic flowmeter. Three years later in 1958, Knapp (KNA) developed an instrument which was based on the pulse repetition frequency method (sing around method). With the advancements of the semiconductor industry beginning of the 70's, flowmeters from the US-based company Westinghouse, and later from others, were available which facilitate the direct transit time difference method (leading edge method). This type of ultrasonic flowmeter makes use of the difference in the time for a sonic pulse to travel a fixed distance; first against the flow and then in the direction of flow. This carries the advantage that the measurement is virtually independent upon the velocity of sound. In the late 90's, the Swiss company Rittmeyer refined the direct transit time difference method further. They applied correlation techniques in order to define the transit time difference more reliably. Transit time flowmeters have been developed to a sophisticated level over the past decades. It seems that further developments will work into more reliable signal detection algorithm, into the functionality of the instruments especially with respect to telemetized possibilities, and into difficult applications.

Hot tapping at North Umpqua Hydroelectric Power Plants, USA:

Three hydroelectric power generating plants, located in south central Oregon, are owned and operated by PacifiCorp, one of the US West's largest electric utilities. In order to bring the 185-megawatt (MW) North Umpqua Hydroelectric Project into compliance with water rights according to Federal Energy Regulatory Commission (FERC) regulations, five (5) four-path acoustic transit time flowmeters were installed in steel pipe penstocks. Requiring a continued energy production without the opportunity of dewatering or stopping the flow, hot-tapping was applied. At present time, these flowmeters are only used to provide local discharge monitoring. In the future, PacifiCorp plans to upgrade these to provide telemetric indication and alarms. Since the installation is performed according to IEC-41 or ASME PTC 18-1992 standard [IEC, ASM] and favorable straight run conditions exist at all five penstocks, the flow measurements provide the accuracy needed to verify unit efficiency after upgrades or continuous efficiency monitoring, such as a part of a condition monitoring system.

Hot-Tapping

Hot Tapping is the process of introducing new acoustic transducer into a pressurized steel penstock; usually where no unit down-time for economical or scheduling reasons can be asked for. A common concept of hot tapping, applied by several other suppliers, is based on a weld-on-boss hot-tap (Figure 1). The permanently installed valve assembly allows for complete installation; drilling holes and transducer insertion, without dewatering the penstock. An advantage of this concept is that after having drilled a simple hole the transducer can already be inserted. However, the common concept has some major weaknesses, such as the limitations of the weld on boss for high head pressures, the need of a weld-on-boss and a valve for each sensor, and the longitudinal axis of the transducer is defined by welding.



a) b) c)

Figure 1: Weld-on Hot-Tapping: a) A weld-on boss and installed transducer requiring a valve; b) The drilling process; c) the process of inserting a transducer. (Source for b) and c): [Krohne AG])

The design of the new “drill and tap” hot-tapping machine for high head pressure was derived from the analysis of the advantages and disadvantages of conventional weld-on-boss hot tapping concepts and from the three additional requirements:

- Working pressure; installation of wetted acoustic transducer up to a pressure of 35-bar (500 psi).
- Transducer; use of screw-in transducers from the standard product line requiring no access from the inside.
- Serviceability; use of the transducer exchange device from the standard product line.

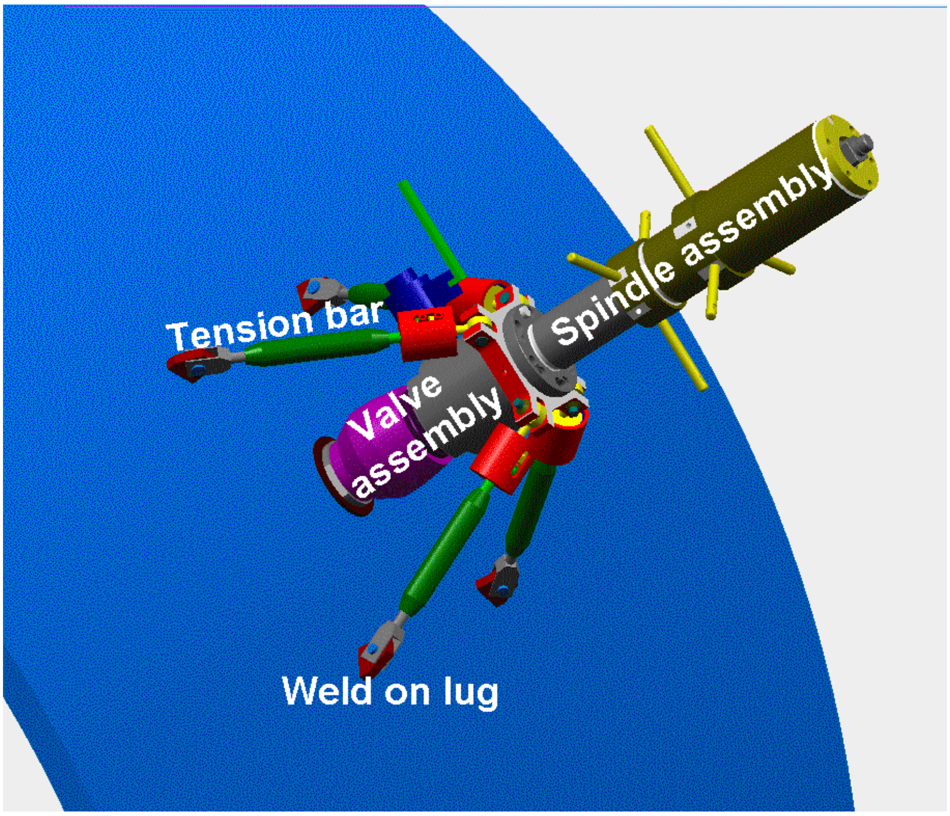


Figure 2: The “Drill and Tap” Hot-Tapping machine with the key components

The “drill and tap” hot-tapping machine is essentially made up of 5 main components which are, the weld on lugs, the tension bars, the valve assembly, the spindle assembly, and the drilling machine. The sum of the four different forces acting on the hot-tapping machine (pressure inside the penstock, axial cutting forces, forces from the drilling machine, and additional forces eventually imposed from the operator) showed that the required length of the circumferential weld seam to scope with these forces would call for an impractical large diameter of a conventional weld-on-boss (Figure 1). In order to overcome this inherent problem, these forces are taken up by 4 lugs; which are temporarily welded to the penstock. The welded joint were generously dimensioned with a safety factor of four. The valve assembly is then, with help of the tension bars, connected to the lugs and tightened so that it presses the hot-tapping machine with an axial force of approximate 28kN to the penstock. In addition, a centering ring is tack welded to the penstock to insure that the machine is placed at the right position and it does not slip away during the set up procedure (Figure 3).

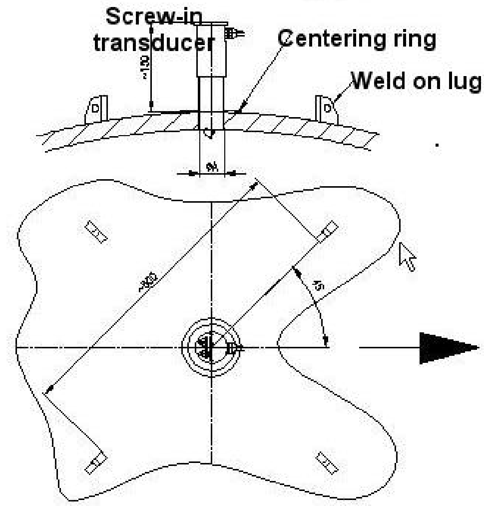


Figure 3: Weld on lugs and centering ring temporary welded as well as installed acoustic screw-in transducer.

The tension bars assure that after the lugs are welded, the hot-tapping machine can be easily aligned. A spring mechanism was incorporated into the tension bar for safety reasons. In order to keep the machine as simple as possible, the spindle assembly chucks the drill bits, the chamfer, the tap, and the complete acoustic transducer. The spindle assembly consists of the working spindle and three threaded cylinders. The working spindle, where the drilling machine is attached, rotates the two drills (pilot and main), taps, and also screws in the transducers. The three threaded cylinders are needed to pass the tools through the valve and feed it into the penstock. For safety purposes, the spindle assembly cannot be unbolted from the valve assembly as long as the valve is open. The standard “drill and tap” hot tapping machine comes with a conventional two-speed drill. As a further safety precaution, the working spindle and the drilling machine are connected by means of a clutch. During the designing process much attention was paid to safety issues. FMEA (Failure Mode and Effects Analysis) was performed on the design to insure that the greatest safety possible for operators and materials could be assured.

Figure 4: The screw-in process of the transducer

In principle, the concept “drill and tap” can be redesigned so that penstocks with more than 35-bar (500psi) head pressure can be equipped with acoustic screw-in transducers while generating power. One limiting factor will be the weight of the hot-tapping machine itself, if too heavy, it would complicate the practical handling on site. The “drill and tap” concept offers several major improvements over conventional hot-tapping. First, the welded joints are not critical for the weld on lugs and only temporary. Thus there are no requirements for the welded joint concerning corrosion, fatigue, leakage, or weld distortion. Second, it eliminates the need for expensive weld-on bosses and valves. Only simple, inexpensive lugs and centering rings are needed which lower the material cost considerably. Third, the hot-tapping machine can be aligned after the welding is done, simply by adjusting the tension bars.

Hot-Tapping meeting installation procedure according to IEC 41/ ASME PTC 18-1992

Any installation according to IEC 41 or ASME PTC 18-1992 standard [IEC, ASM] requires the layout of transducer locations and measurement of the as-build dimensions be done using accurate methods. The code also defines that the shape of the penstock and its representative diameter be measured several times at five reference sections, on both sides of the transducer and in the middle plane. When hot-tapping, the path length can not be measured directly. The use of a total station theodolite is certainly the most effective and accurate method. This surveying system includes angle and distance measurement as well as a personal computer to carry out all calculations. The accuracy of the angle measurement is ±5 seconds; the distance measurement is ±0.75mm. The installation of multi-path ultrasonic flowmeter can be summarized into the following steps:

- Measurement and analysis of the geometry of the penstock
- Calculating the x-y-z coordinates of the transducers based on the shape of the penstock
- Marking of the transducer locations
- Hot-tapping and installing the transducers
- Measuring of the as-builds

The exact shape of the penstock is derived from measuring the coordinates of 40 reflecting targets placed on the surface of the penstock and fitting them to a mathematical shape describing an elliptical cone. Using Least Square Fitting and Taylor Development [COO], the geometrical parameters can then be determined. With these results, the location of the transducers can be calculated based on the angles of 18° and 54° given in the IEC 41 or ASME PTC 18-1992 standard [IEC, ASM], and standard path angle of 45°. Using the integrated laser pointing system of the theodolite, all locations of the transducers were located and center punched. Since only one side of the penstock can be viewed at one time, the theodolite is moved from one side to the other and back with reference to the five reference points visibly from both sides.

Figure 5: Left; Acoustic transducer with reflecting targets for final measurement. Right; One side of the penstock with 20 reflecting targets and 4 acoustic transducers.

The next steps is to weld the lugs and the centering ring to the penstock (Figure 3). Then mount and align the hot-tapping machine, drill the hole, and tap the thread. The alignment of the hot-tapping machine is important to ensure the longitudinal axis of the transducer is intersecting the center line of the penstock. Finally, the transducer is inserted and the machine is removed. When all of the transducers are installed, the final geometrical parameters required for the ultrasonic flowmeter (as-builds) are measured with the total station theodolite. This generates; path length, path angle and the abscissa of the paths. To measure the final location of the transducers, a reflecting target is placed over the sensors. The geometrical representation of the paths also allows calculation of the as-build position and determines the as-build weighting factors for the integration of the flow rate according to the OWICS method [VOS].

Conclusion

The newly developed and applied "drill and tap" hot tapping was proven with success. The system allows to install wetted transducers up to 35-bar (500 psi) head pressure. Standard screw-in type transducer are used and they can be serviced with the standard transducer exchange device. A high degree of safety was consequently designed into this concept, since an erroneously event could have disastrous consequences for both the supplier and customer. Meeting installation requirements according to IEC-41 and ASME PTC 18-1992 standard [IEC, ASM], a higher standard for hot-tapping has been realized with the newly developed "drill and tap" hot-tapping of Rittmeyer.

Future Project; Aswan High Dam, Egypt

The Aswan High Dam is used for creating hydro-electricity for Egypt. The power plant has a total installed capacity of 2100 MW, representing about 18% of Egypt's total generation capacity [HYD]. It consists of 12 Francis turbines and hydro-generators each rated at 175 MW. The US Agency for International Development (USAID) is funding the project to computerize the control facilities at the power station. These upgrades serve to extend the life of the power generation facilities by 30 years and increase its efficiency by more than 5%. As part of this upgrade, two out of the twelve penstocks will be equipped with 8-path acoustic transit time flowmeters according to IEC-41 or ASME PTC 18-1992 standard [IEC, ASM].

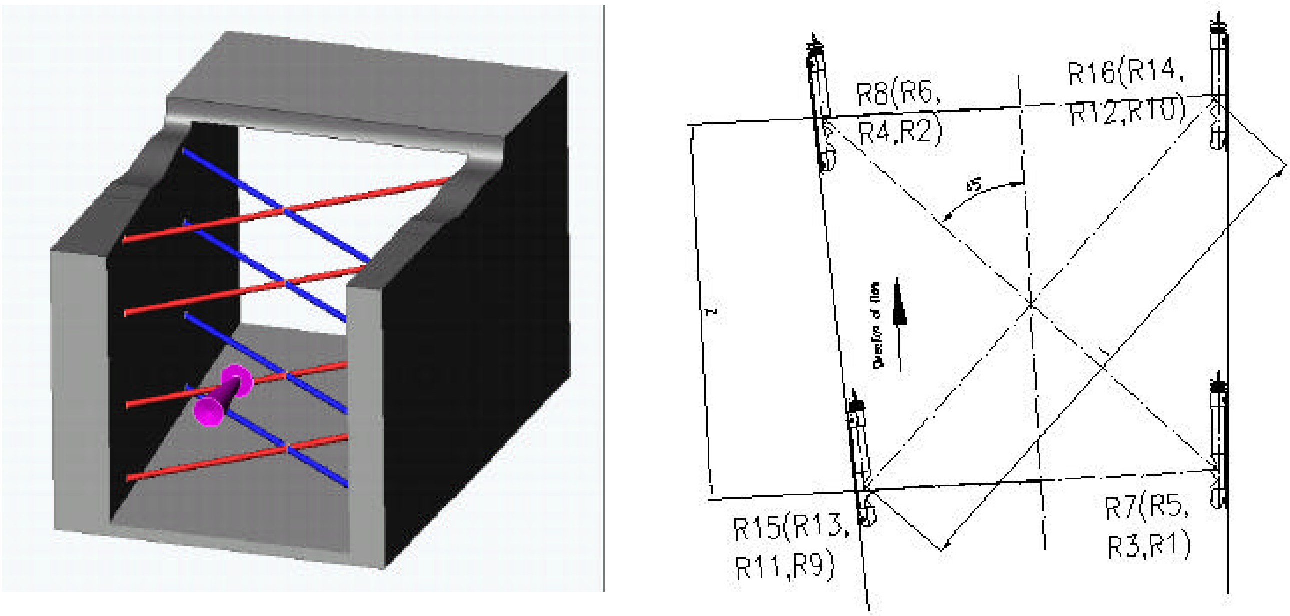


Figure 6: Left; Measuring section with four acoustic elevation planes (or two crossed planes). Right; Acoustic transducer with redundant oscillator

The intakes for the turbines at the Aswan High Dam are concrete-lined, rectangular conduits where the width of the cross-section varies. Figure 1 shows a three dimensional representation of the conduit. The dimension of the height is 8.6m and the width measures from 7.7m downstream to 8.6m upstream of the measurement section. Because the conduit can not be accessed readily, internally mount acoustic transducers have been chosen with redundant oscillators. If failure occurs to one of the oscillator the second oscillator can be used. This feature makes the flowmeter system more reliable. The acoustic paths are arranged on two measurement planes at four elevations. This arrangement has been chosen to minimize the cross flow influence, ensuring an accuracy of 0.5%. The paths have been arranged in a way that all acoustic path length are of equal length. Each of the path will measure an average path velocity along its acoustic path. The four elevation planes have been placed so that the processing of the path velocities can be done according to the well known

Gauss-Legendre-quadrature integration formula described in IEC 41 or ASME PTC 18-1992 standard [IEC, ASM].

$$Q = k \cdot \frac{D}{2} \sum_{i=1}^{N} W_i \cdot \overline{v}_{axi} \cdot L_i \cdot \sin\varphi_i \qquad (1)$$

k:	Correction coefficient
D:	Dimension of the duct perpendicular to the acoustic path
W_i:	Weighting coefficients
v_{axi}:	average path velocities
L_i:	Acoustic path length
f_i:	Angle of the acoustic path

Does a systematic error exist from the measuring section?

In order to minimize systematic errors, transit time flowmeters are normally not installed in measurement section with variable cross-sections. In this case, however the measuring section had to be placed where the cross-section is tapered. Preliminary studies show that the introduced error might not be large, yet requiring a measurement uncertainty of the flow rate of only 0.5%, it should be investigated in more depth. A systematic error can be calculated if the velocity profile (vector field) is known. Based on fictively assumed acoustic paths, and the average path velocities, the flow rate is calculated according to Equation 1. On the other hand, the flow rate can also be calculated numerically based on the same velocity vector field. Knowing that the latter is the true flow rate, the difference can be quantified and a correction factor can be introduced. There are in principle three different ways to acquire a velocity vector field for this given situation for further numerical analysis. These are analytically given expressions, laboratory measurements or CFD (Computational Fluid Dynamics) simulations. It is intended to estimate the systematic error based on CFD simulations. Interesting results on the velocity profiles, path velocities, flow rate calculations are expected.

Acknowledgement

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References

IEC	Field acceptance tests to determiene the hydraulic performance of hydraulic turbines, storage pumps, and pump-drives. International Standartd CEI/IEC 41, Third Edition 1991-11
ASM	Hydraulic Turbines, Performance Test Codes ASME PTC 18-1992 The American Society of Mechanical Engineering, 1993
VOS	Analyse und Fehleroptimierung der mehrpfadigen akustischen Durchflussmessung in Wasserkraftwerken (in German) Alexandre Voser Dissertation ETH Zürich Nr. 13102, 1999.
HYD	Hydropower & Dams Issue four, page 4, 2000
ETT	Bestimmung von Korrekturfaktoren für eine Ultraschalldurchflussmessverfahren in Rohrleitungen mit Störungen (in German) Siegbert Etter Dissertation at the university of Stuttgart, 1982
KNA	Geschwindigkeits- und Mengenmessung strömender Flüssigkewiten mittels Ultraschall (in German) C.Knapp Dissertation ETH Zürich Nr. 2795, 1958.
COO	Control Surveys in Civil Engineering M.A.R. Cooper Collins Professional and Technical Books, 1987
Krohne AG	Product literature Hot-Tapping (in German)

The Authors

Stefan Baumann completed a B.Sc. in Mechanical Engineering from the University of Applied Science in Lucerne, Switzerland in 1992. He graduated from the Case Western Reserve University in Cleveland, Ohio, USA and received his M.Sc. in 1998, where he specialized in flow visualization techniques. A grant for experienced engineers from the Swiss National Energy Foundation allowed him to perform post-graduate work on acoustic discharge measuring devices at the University of Applied Science in Lucerne, Switzerland. He has joint Rittmeyer Ltd. in 2000 as a hydraulic engineer.

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