The Swiss National Energy Foundation Project on Acoustic Discharge Measurement

Project-group "**A**coustic **D**ischarge **M**easurement":

- Swiss Federal Institute of Technology in Zürich
  ETH-Z, Turbomachinery Laboratory, CH-8092 Zürich, Switzerland
  Dr. T. Staubli (Project manager) Tel. +411 632 24 56, Fax +411 632 11 00
  A. Voser Tel. +411 632 67 85, Fax +411 632 11 00
- Swiss Federal Institute of Technology in Lausanne
  EPFL, IMHEF, Av. de Cour 33, CH-1007 Lausanne, Switzerland
  J.-E. Prénat Tel. +41 21 693 25 10, Fax +41 21 693 35 54
  Ch. Bruttin Tel. +41 21 693 25 30, Fax +41 21 693 35 54

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Summary

The project's activities aimed at a prediction of measuring accuracy in the state of planning and evaluation of the instrumentation, as well as optimisation of path number and orientation for a given disturbed flow situation. Furthermore, a series of tools were provided for a detailed analysis of measuring uncertainties subsequent to performed discharge measurements. To achieve these goals laboratory tests, numerical analysis, theoretical studies and field tests were performed.

From a critical analysis of the IEC41 integration methods stems a proposal for an improved procedure which eliminates systematic errors by calculating the weights from the surveying data of the individual paths.

Résumé

Les activités du projet ont eu pour but d'une part de prédire la précision de la mesure au stade des études préliminaires et du choix de l'instrumentation et d'autre part de déterminer le nombre de pistes optimum ainsi que leurs orientations selon la perturbation de l'écoulement inhérent à chaque nouvelle installation. Une série d'outils a été développée pour permettre une analyse détaillée des incertitudes de mesure subséquemment à des mesures de débit. Pour atteindre ce but, des essais en laboratoire, des analyses numériques, des études théoriques et des mesures sur sites ont été entrepris.

Sur la base d'une analyse de la méthode d'intégration proposée dans la norme CEI 41, une proposition de modification permettant d'éliminer une erreur systématique est formulée. Cette nouvelle méthode permet de calculer les poids nécessaires à l'intégration sur la base des relevés géométriques de chaque piste.

1. Developed and available tools

- To perform laboratory and field measurements two sets of acoustic discharge measuring equipment were available. For eight paths measurements in high and low head power plants a set of feed-through and inside mount transducers was acquired.
- For fast and accurate positioning of acoustic transducers and for an accurate determination of the cross-section areas a geometrical survey system with two servo controlled theodolites was developed (Voser [2]).
- Numerical programs for integration along simulated acoustic paths in a given flow field were developed. These programs allow estimation of the measuring accuracy to be expected as a function of geometry, flow conditions and number of acoustic paths.
- Finally, two codes for numerical flow computations (Fidap and TASCflow) were applied to calculate disturbed flow conditions in conduits and local flow fields around protruding transducers.

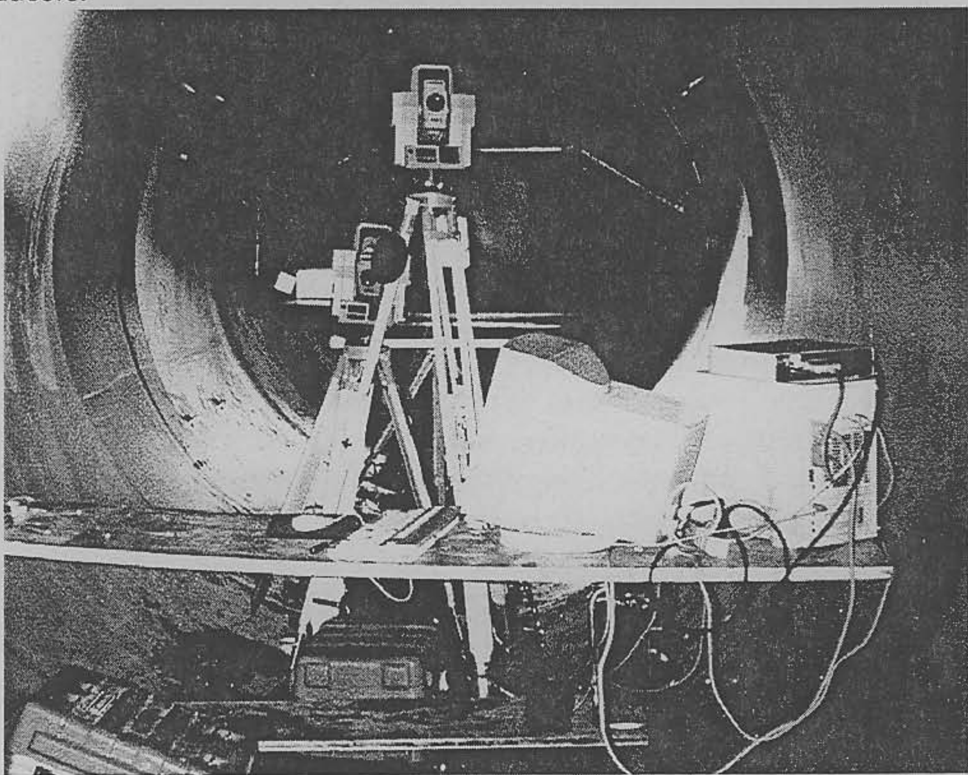

Fig. 1 Surveying system with two theodolites and control computer in a 2.8 m conduit

2. Investigations completed in course of the project

- Comparative tests were performed in the laboratory confirming the accuracy of an eight paths metering section even for heavily disturbed flow conditions (IGHEM-Montreal 96: Bruttin Ch., Prénat J.-E., "Experience de mesures par débitmètre US"). Tests were conducted with elements at varying distances upstream of the metering section such as 45° and 90° bends, an eccentric convergent, a swirl generator, and a simulated valve.

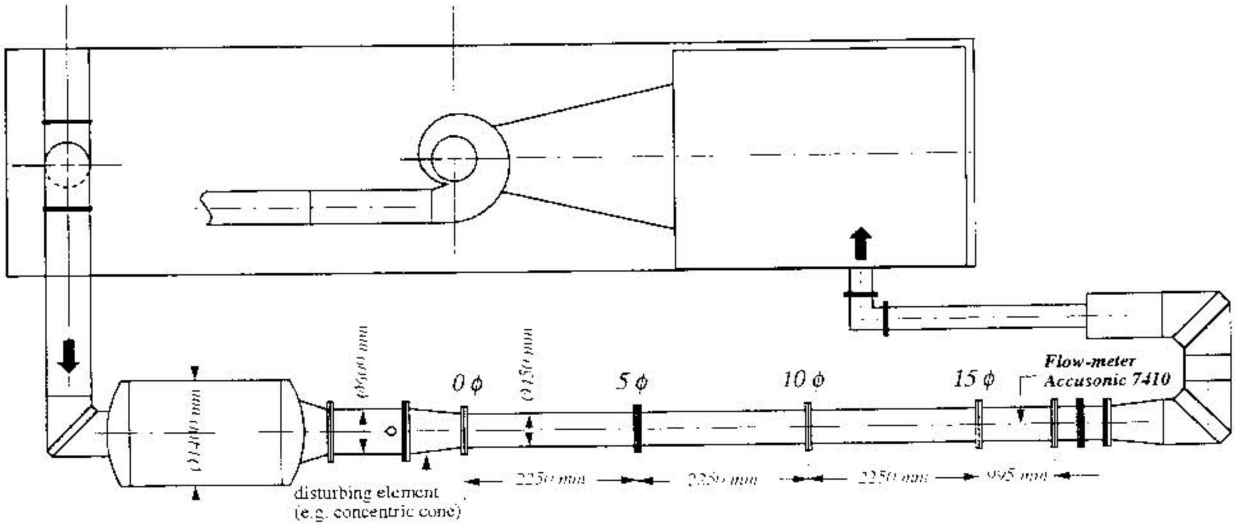

Fig. 2   Test rig employed for comparative tests in the laboratory

- A series of field measurements were performed in hydraulic power plants. The first measurements were with emphasis on the geometrical survey. An excellent comparative test with volumetric method could be performed in the plant of Pradella-Martina (Mancal et al.[3]). An other comparative test was successfully performed with current meter measurement under most unfavourable installation and flow conditions in the plant of Augst at the river Rhine.

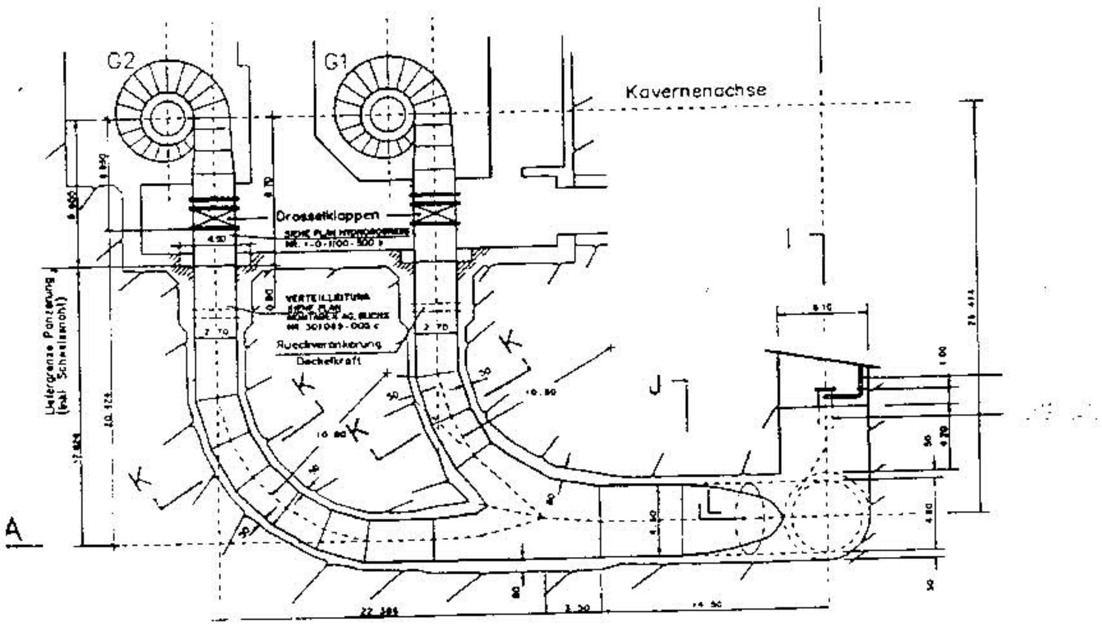

Fig. 3   Layout of the power house of Martina

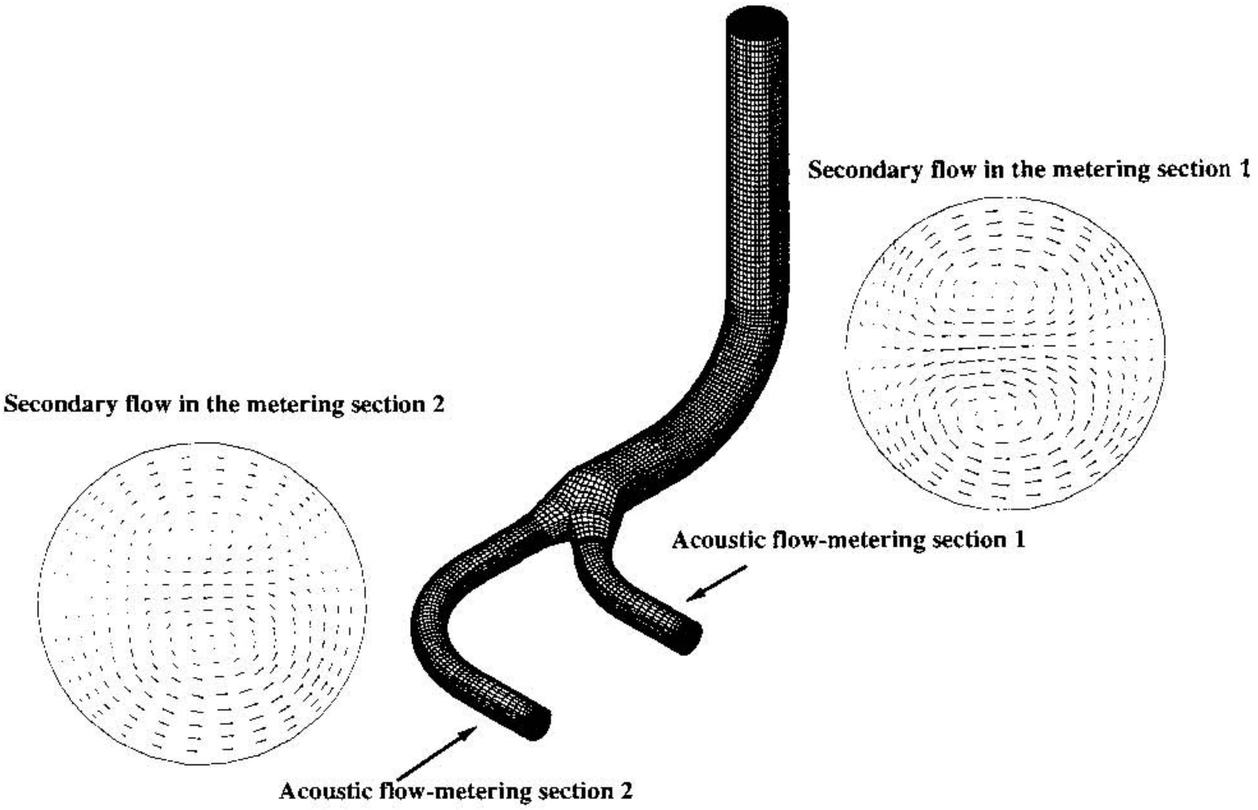

Fig. 4 *Martina power plant: Grid used for CFD-calculations and the induced secondary flow in the metering section (looking upstream)*

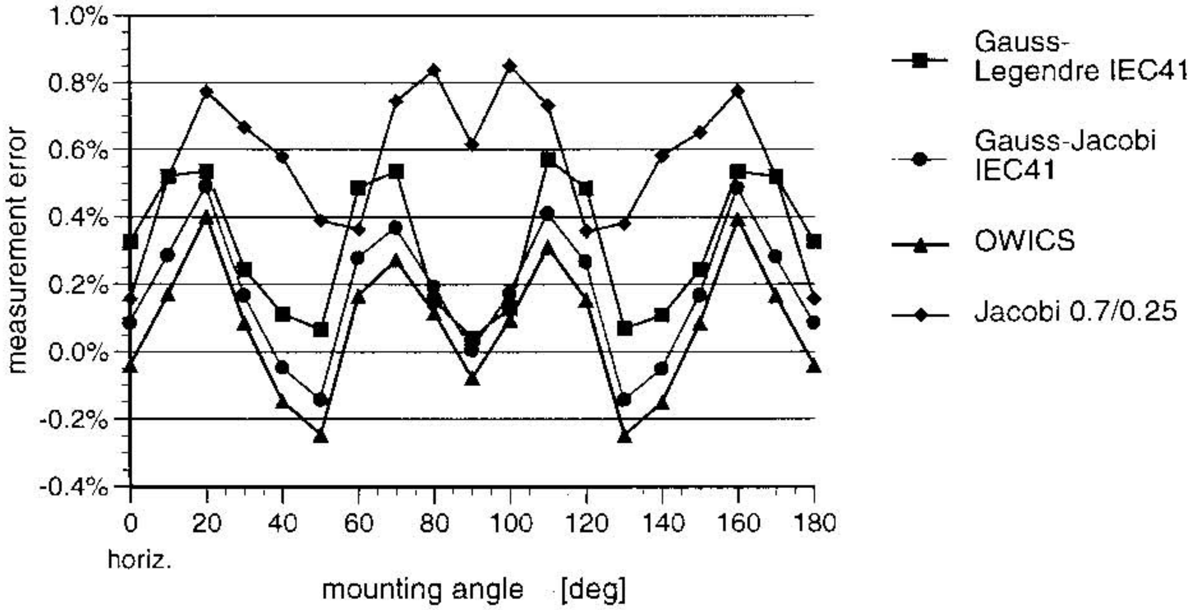

Fig. 5 *Simulated influence of the mounting angle on the reading of an eight path acoustic flow meter behind a 90° bend. (Simulation based on LDA-measurements: Enayet, Gibson, Taylor, Yianneskis, NASA Contractor Report 3551, 1982)*

- Numerical flow computations were performed in order to simulate disturbed flow conditions typically encountered in power plants (see Fig. 4).
- The local flow field around protruding transducers was computed with TASCflow (k-ε solver). The velocities along the simulated acoustic paths were integrated and the calculated discharge was compared to the theoretical discharge with undisturbed boundary layers and no protrusion (IGHEM-Montreal 96: Voser A., "CFD-Calculations of the protrusion effect and impact on the accuracy the acoustic discharge measurement").
- Experimentally the protrusion effect was investigated performing 2D-laser measurements along the acoustic path in the boundary layer of an open channel. These measurements were used to verify numerical flow calculations.

3. Improvement of the integration method for circular sections

Discharge through the conduit is determined from integration of individual path readings, resulting in an equation which sums up the weighted path readings. Usually, the integration for a multi-path acoustic flow meter is performed according to IEC 41 Appendix J [4].

The two quadrature integration formulae used are

$$Q = k\frac{D}{2}\sum_{i=1}^{n} W_i \bar{v}_{ai} L_{wi} \sin\varphi \qquad (1)$$

for rectangular and circular sections and

$$Q = \frac{D^2}{2}\sum_{i=1}^{n} W_i' \bar{v}_{ai} \quad \text{with} \quad W_i' = W_i \sin\alpha_i \qquad (2)$$

for truly circular sections with the paths positioned exactly at the specified locations, where α_i defines the angular location of the path i.

With the distances d_i of the acoustic paths to the centreline Eq. (2) can also be written as

$$Q = \frac{D}{2}\sum_{i=1}^{n} W_i \bar{v}_{ai} \sqrt{D^2 - 4d_i^2} \qquad (3)$$

One of the limitations of the integration methods described in IEC 41 is the fixed weighting of the paths and thus the need for a very accurate positioning of the transducers in relation to the distances d_i. It has been shown (Grego [5] and, more recently, Sugishita et al. [6]) that such a misalignment of the acoustic paths in conjunction with fixed weights can lead to relative errors of several thousands. This limitation can be overcome by calculating the weights individually from the surveying data for a 4-path acoustic plane with:

$$W_1 = \frac{g_1 D^2 (d_3 + d_4 - d_2) - g_2 d_2 d_3 d_4}{(1 - 4d_1^2/D^2)^\kappa (d_1 - d_2)(d_1 + d_3)(d_1 + d_4)}$$

$$W_2 = \frac{g_1 D^2 (d_3 + d_4 - d_1) - g_2 d_1 d_3 d_4}{(1 - 4d_2^2/D^2)^\kappa (d_2 - d_1)(d_2 + d_3)(d_2 + d_4)}$$

$$W_3 = \frac{g_1 D^2 (d_1 + d_2 - d_4) - g_2 d_1 d_2 d_4}{(1 - 4d_3^2/D^2)^\kappa (d_3 - d_4)(d_1 + d_3)(d_2 + d_3)} \qquad (4)$$

$$W_4 = \frac{g_1 D^2 (d_1 + d_2 - d_3) - g_2 d_1 d_2 d_3}{(1 - 4d_4^2/D^2)^\kappa (d_4 - d_3)(d_1 + d_4)(d_2 + d_4)}$$

With the constants κ, g_1 and g_2 and the distances d_i listed in Table 1, the weights of the Gauss-Jacobi method from IEC 41 (sometimes also called Tschebyscheff method) are matched exactly. Numerical simulations have shown that path misalignments up to 2% do not affect the accuracy of the acoustic discharge measurement if Eq. (4) is used together with the quadrature integration Eq. (3) and the measured distances d_i.

Another source of errors when using the Gauss-Jacobi-Method is the integration error for fully developed turbulent profiles in circular sections, the most important flow regime for the acoustic discharge measurement.

Depending on the Reynolds number and the wall roughness, specified by the relative sand roughness ks/D, the flow varies from hydraulically smooth to completely rough with a transition region in between.

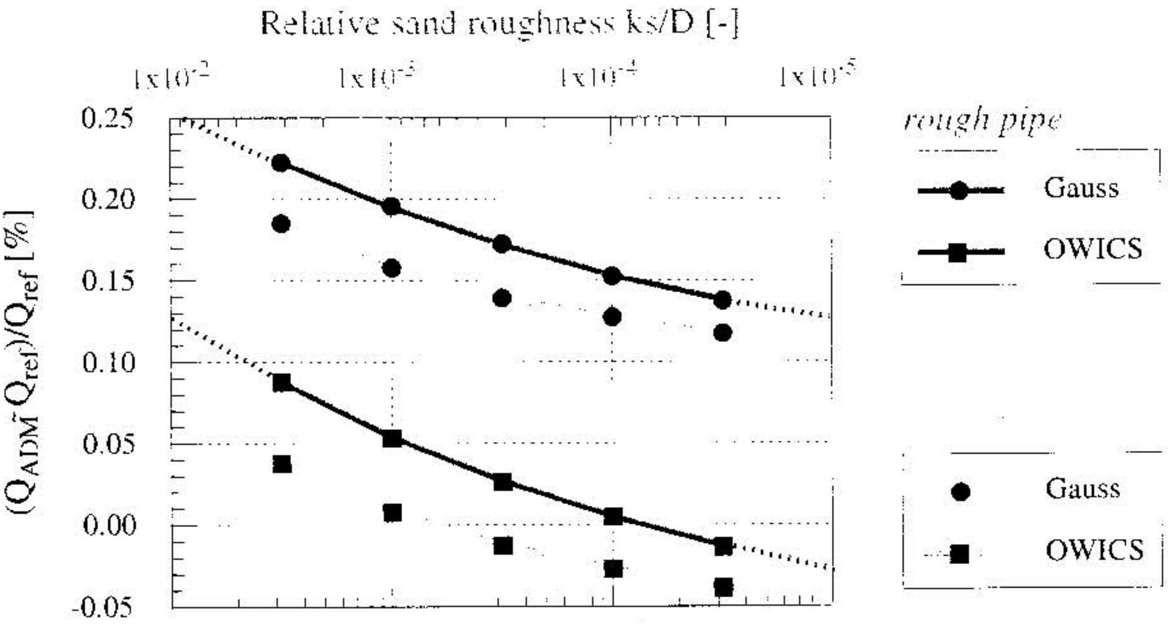

Fig. 6 Integration error of the eight paths acoustic discharge measurement for fully developed turbulent velocity profiles

Our calculations were conducted within the hydraulic smooth flow regime, in which the velocity distribution is a function of the Reynolds number only and the completely rough flow regime depending only on the wall roughness. By simulating the acoustic discharge measurement with logarithmic laws for both velocity distributions, errors up to 0.25% were computed.
To avoid these errors an optimised integration method called OWICS (**O**ptimal **W**eighted **I**ntegration for **C**ircular **S**ections) with a slightly different weighting of the acoustic paths was developed. According to Fig. 6 the integration errors with the OWICS method are reduced by approximately 0.15% over the full range of Reynolds numbers and relative sand roughness, ks/D. The new integration method is mathematically comparable to the Gauss-Jacobi method, therefore the weights are also calculated with Eq. (3) and the coefficients listed in Table 1.

	Gauss-Jacobi IEC41		**OWICS**	
κ	0.5		0.6	
g1	0.0981748		0.0900812	
q2	1.5707963		1.5133647	
k	1		1	
	paths 1 und 4	*paths 2 und 3*	*paths 1 und 4*	*paths 2 und 3*
$d_i/(D/2)$	0.809017	0.309017	0.809017	0.309017
W_i	0.369317	0.597667	0.365222	0.598640

Table 1 Constants and weights for the quadrature integration methods

Note that for both methods the acoustic paths are placed exactly at the same positions. This allows direct comparisons between the two methods for already installed flow meters.

4. Conclusion

In course of the project experience was collected with respect to a series of measuring uncertainties of the acoustic discharge measurement. Analysis of the associated phenomena finally led to the development of specific tools enabling the quantitative prediction of measuring uncertainties for individual test situations in power plants.

References

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