FLOMEKO 2003
**11th IMEKO TC9 Conference on Flow Measurement**
Groningen, NETHERLANDS, 12 - 14 May 2003

# NOVEL TECHNIQUE FOR CALIBRATION PIPE PROVER MEASURING VOLUME

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Abstract
The measuring volume of a pipe prover used as a volumetric standard measuring device in the hydrodynamic test field was calibrated by a geometrical measuring method, having been implemented for the first time. Using incremental length measuring devices for the axial and lateral direction a more precise characterization of the volume is feasible.

## Introduction

The hydrodynamic test field will become the national primary standard for the realization and measurement of flow rate, volume and mass of flowing liquids [1]. To warrant the low expanded measurement uncertainty of only 0,02 %, weighing systems with diverters [2] and a pipe prover used as gravimetrical and volumetric standard measuring devices in the test field were installed. By direct comparison measurements between these standards, it will be possible to identify and quantify in concrete values the different influence quantities on the measurement uncertainty of test field.

Although the manufacturers have specified certain values for the standard measuring devices, for example for measurement uncertainty and reproducibility, it is compulsory to recalibrate the standard measuring devices at regular intervals in order to ensure the low measurement uncertainty of the test field continuously. For this purpose each weighing systems in the test field is equipped with a loading device [3]. This allows a recalibration of the weighing instruments by adding calibrated weight sets at any time. For the recalibration of pipe prover, the PTB implemented two different measuring methods. One method is well known, it uses the traceability to a mass standard, i. e. the measuring volume is determined by weighing the mass of the displaced water. The technical realization of the other method is a world novelty and unique in its kind and will be presented here. It is based on traceability to a length standard, i.e. the measuring volume of the pipe prover is determined by measuring the geometry.

## Pipe prover

As volumetric standard measuring device, a so-called 24"-compact prover was installed in the test field. Determination of the flow rate to be examined is achieved by displacement-time measurement with the individual functions of the pipe prover being controlled and monitored by an electronic system which is part of the scope of supply. A schematic chart of the pipe prover is shown in Fig. 1.

The pipe prover consists of a precision cylinder where a freely movable piston with a disk valve is mounted. The valve is centrically arranged in the piston, and is connected with the piston actuator cylinder via a bar. In the actuator cylinder, pressures/forces are built up by the gas of the pneumatic spring plenum and by the oil of a hydraulic pump. The forces built up by these two media act into the opposite direction and allow different functions to be carried out, like furnishing the pressure needed to open or close the disk valve, retracting the measuring piston after each run and ensuring minimum pressure differential at both sides of the piston.

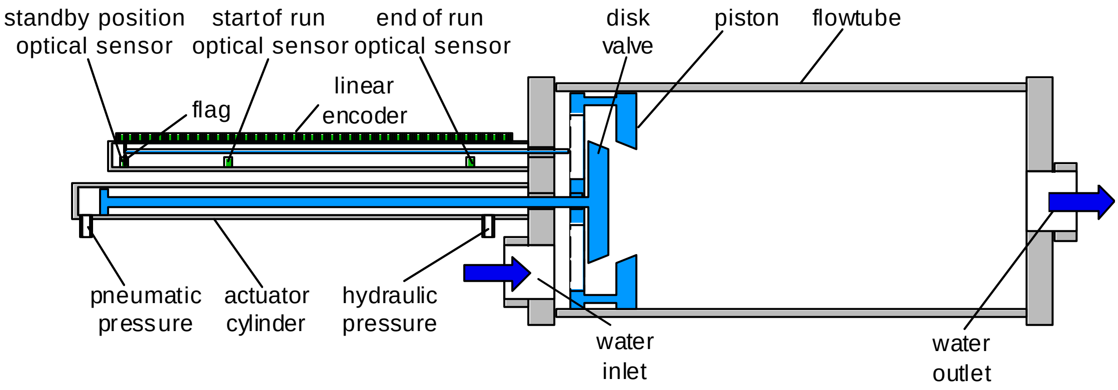


Figure 1: Schematic view of pipe prover (in standby mode)

The position of the piston is ascertained via three slotted optical sensors installed outside the cylinder (see also fig. 2). The interrupt flag which is carried through the sensors is rigidly linked with the piston via a bar. The standby position of the piston - its on the water inlet side - is detected by the first sensor. The spatial limits of the measuring volume and therefore the start and the end of a measuring run/stroke are defined by the respective positions of the second and third optical sensors.

The standby position is maintained by the oil pressure built up by the hydraulic pump. In this position, the disk valve in the piston is open, and the water streaming into the cylinder flows almost unobstructedly through the piston. For starting a measurement run, the hydraulic pressure in the actuating cylinder is reduced by opening a magnetic valve, and the gas pressure pushes the disk valve into the piston. The closed piston is now accelerated in the downstream direction. Subsequent to the acceleration phase which comes to an end after a few centimeters, the piston moves through the cylinder at constant speed.

When the second optical sensor is reached, time measurement starts off, and also the registration of the indication of the flow meter to be calibrated, and is stopped when the third sensor is reached. With the period of time measured in this way, and with the known measuring volume between the two sensors, the flow rate is finally determined in volume per time unit. When the piston had passed the third sensor, the above-mentioned magnetic valve is closed again. The pressure of the hydraulic oil building up in the actuating cylinder now opens the disk valve and pulls the piston back into the counter flow position. This way, an uninterrupted flow is guaranteed during the continuously repeating measuring cycles.

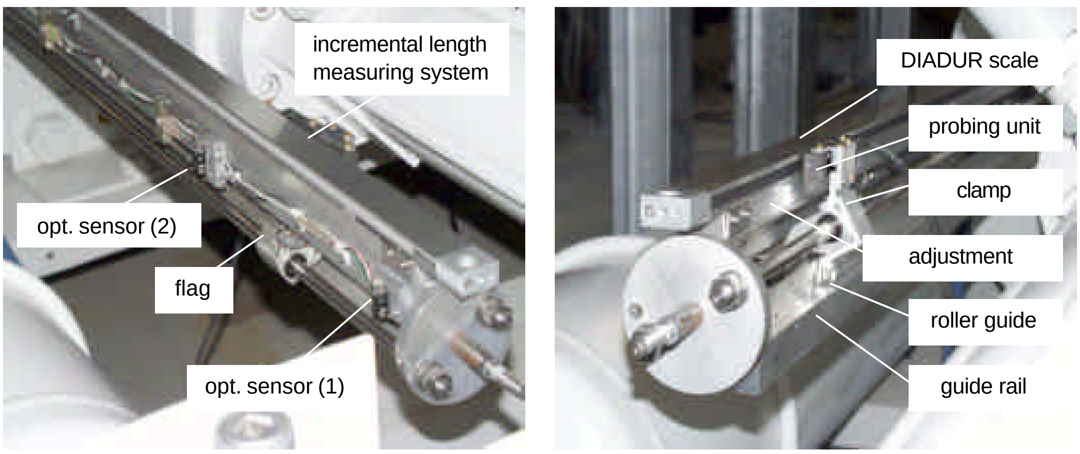


Figure 2: Arrangement of optical sensors and incremental length measuring system

The temperature of water in the pipe prover is measured by temperature sensors which are mounted into the water inlet and outlet pipe. To measure the temperature of the flow tube, four sensors were attached to the exterior surface of the cylinder which was heat-insulated by covering it with foam mats 2 cm thick. Further technical details of the pipe prover are given in Table 1.

The scope of functions of the pipe prover was extended by PTB by an incremental length measuring system/linear encoder, which will be employed for testing the movement of the piston and for the high-accuracy determination of the piston position when measuring the inside diameter of the cylinder, see figure 2. To warrant the narrow mounting tolerances of the length measuring system, the housing of the DIADUR glass scale was fastened to the device via an adjustment guide and the probing unit provided with roller guides. The length measuring system with a measurement length of 1240 mm allows, together with the position display, indication steps of 1 µm at a measurement uncertainty of ± 3 µm.

Table 1: Manufacturer's specifications for pipe prover

| | |
|---|---|
| nominal diameter | ND 600 (24") |
| volume flow range | 1,6 – 1600 $m^3/h$ |
| measuring volume | approx. 250 l |
| measuring pipe diameter | approx. 647 mm |
| length of measuring stroke | approx. 759 mm |
| length of measuring pipe | approx. 1670 mm |
| length | 4,543 m |
| width | 1,991 m |
| height | 1,257 m |
| weight | 4535 kg |

Measuring device for geometrical calibration

Geometrical calibration of the measuring volume is carried out by determining the values of the cylinder's inside diameter and by determining the distance between the second and third optical sensor [4]. The inside diameter values were measured by using a measuring device shown in figure 3. The device is attached to the front side of the piston while the piston is open and "dry". It consists of two arms linked with each other through a swivel joint. They are made of invar steel which have a very low thermal expansion coefficient of $\alpha = 1 \cdot 10^{-6}\ K^{-1}$. The bottom arm serves as a support and is attached to the piston. In the upper arm, two incremental measuring probes and a displacement unit for positional corrections are installed. The displacement unit ensures that the measuring device covers the maximum diameter and not the distance between two points on the interior side of the

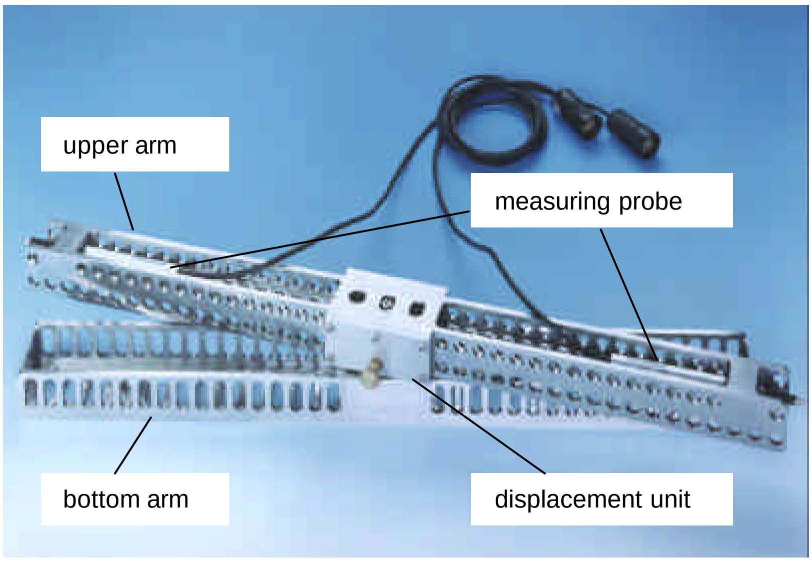


Figure 3: Device for geometrical measurement of the measuring volume

cylinder which lie on a chord. The values furnished by the measuring probes are read into a computer via a PC card with a data rate of 6 Hz. According to the manufacturer, the accuracy of data acquisition is ± 1 µm. The device is 63 cm long and 5 kg in weight. Diameter determination is possible in 12 angular positions at intervals of 15°.

The measurement sequence is as follows: before the measuring device is mounted in front of the piston, it is calibrated by means of a length standard. This standard, also made of invar steel, has, at 20°C, a calibrated inside gauge of 646,959 mm ± 7 µm. Then the measuring device is fastened to the piston and the movable upper measuring arm is adjusted to the maximum diameter and then fixed. With the aid of the hydraulics and pneumatics, the built-on measuring device, is slowly driven through the cylinder – from the position of water outlet to the water inlet position and back. At the same time, the values for piston position, the inner diameter values and the signals of the optical sensors are stored. When the piston is back in the position of water outlet, the upper arm is changed in another angular position and measurement is repeated. After all angular positions are measured, the device is removed, recalibrated and mounted again to the piston for a further cycle of calibration.

<u>Results of geometrical calibration</u>
The switching points of the optical sensors, defining the axial spatial limits of the measuring volume, were determined by moving the flag extremely slow back and forth through the slotted sensors several times. At the same time the switching signal of the sensor and the signal of the incremental length measuring system are recorded. At a switching uncertainty of ± 7 µm, the switching point of the second sensor was determined to be at a piston position of 286,320 mm and the switching point of the third sensor at 1046,767 mm. Therefore, the length of the measuring volume is 760,447 mm ± 10 µm.

A typical result of measurement inside diameter values shows figure 4. Depending on the position of the piston app. 2500 values measured in the horizontal direction of the flow tube are shown. The measurement were done five times in backward and forward direction with recalibration between

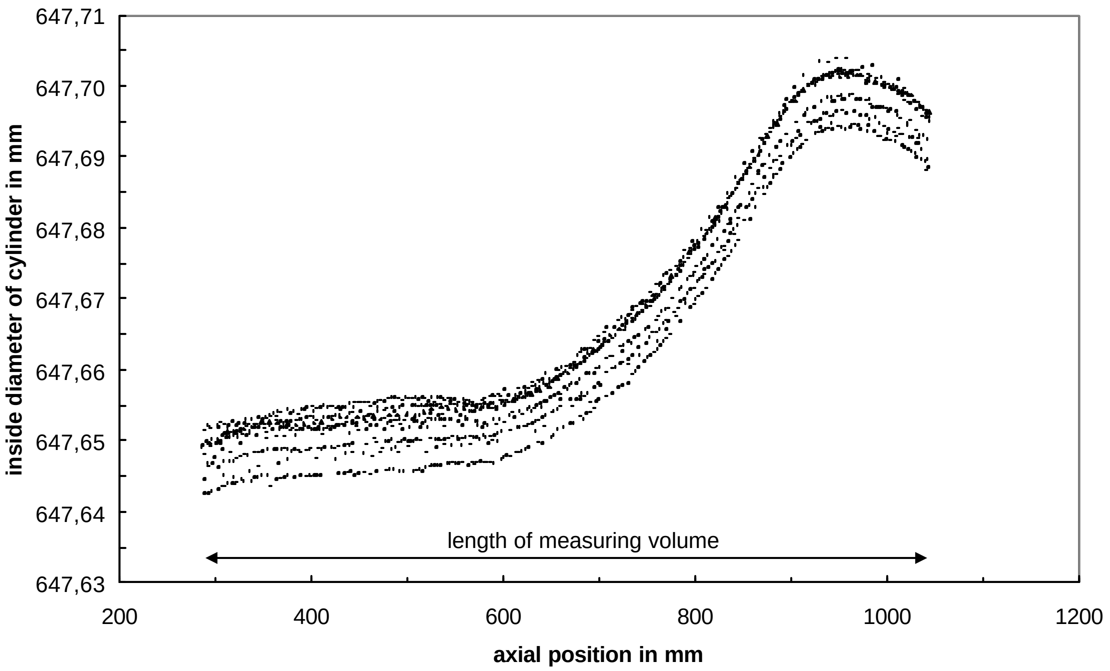


Figure 4: Inside diameter values of cylinder in the horizontal direction depending on axial position of the measuring device

each cycles. The standard deviation measured over the five cycles within a flow tube length of 10 mm was calculated to be lower than 4 µm. The same standard deviation were determined by the measurement in other angular positions.

Figure 5 shows a compilation of results measured in all angular positions; app. 3200 data points are shown. Each data point represents an average value determined over 10 mm flow tube length and five cycles (app. 20 single values). The linear expansion of the measuring volume is plotted also. In all angular positions, smooth variations of the diameter can be observed in the longitudinal direction of the cylinder. The smallest diameter values are measured close to the horizontal, around 15°, and the greatest values close to the vertical, around 105°. At the beginning of the measuring volume, the greatest and smallest diameter values were determined with a spread of 315 µm. At the end, this spread is 189 µm. The largest change in diameter in the longitudinal direction was measured to be 117 µm in the 30° angular position, and the smallest to be 22 µm in the 165° angular position.

The evaluation over all diameter values measured within the measuring volume length yielded a mean inside diameter value for the cylinder of 647,794 mm ± 9 µm. With this mean inside diameter the measuring volume is calculated to be 250629,735 cm³ ± 4 cm³, related to a temperature of 20°C.

This result was compared with the result of a second method for calibration of the measuring volume which is based to traceability to a mass standard. The mass of water contained in the measuring volume and displaced by the piston was determined by a weighing instrument. The evaluation of eleven single measurements by this method yielded a mean value for the measuring volume of 250609,322 cm³. The relative standard deviation yielded by this method was 7,6 cm³. Compared to the result of the geometrical method, a different of only 0,0081 % was measured.

When studying the shape of the curves shown in figure 5 one could assume that the cylinder is of a slightly oval form, and this impression is confirmed by figure 6. In a presentation in polar coordinates, the inside diameters of the cylinder measured in the twelve angular positions at four piston positions (0 mm, 400 mm, 800 mm and 1087 mm) are plotted. To enhance the resolution

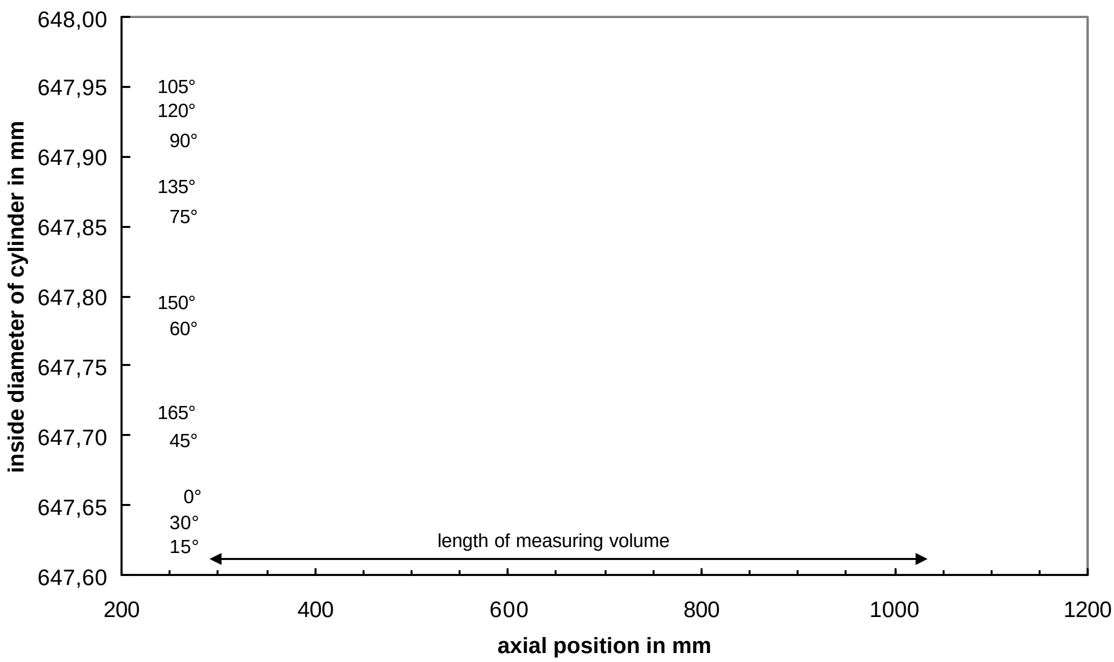


Figure 5: Average inside diameter values of cylinder depending on axial position and angular position of the measuring device

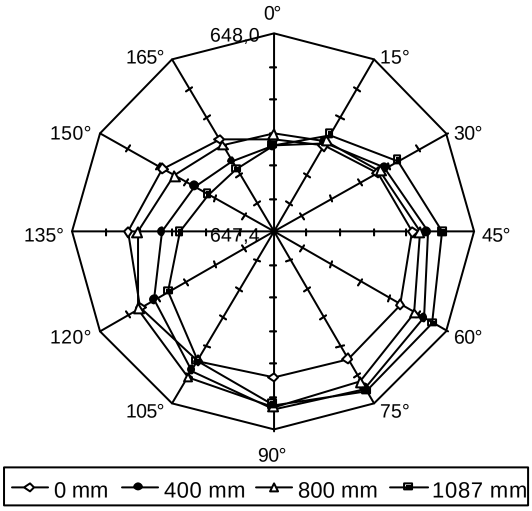


Figure 6: Cylinder ovality at different piston positions

for the analysis, the radial component of the presentation was limited to 0,6 mm. Starting from a diameter value of 647,4 mm in the centre of the diagram, larger inside diameter values of the cylinder are plotted in an appropriately distance from the centre. The marginal area of the polar coordinate plot demonstrates values of 648,0 mm.

In this figure the oval form of the cylinder and changes regarding to size and position of its axes in the longitudinal direction of the cylinder can be discerned. As a reason for these changes, the process of drilling the cylinder and tensions in the cylinder for example could be assume. The tensions might have been caused by exterior threaded rods after the cylinder had been clamped between its two front plates. According to the manufacturer's specifications, the non-cylindricity of the non-clamped cylinder was less than 100 µm.

As this measuring method allows high-resolution geometrical measurement of the cylinder both in the radial direction (incremental measuring probe; different angular positions) and in the axial direction (incremental length measuring system), we make further studies, the slice-by-slice determination of the measuring volume with reference to the existing ovality.

The ovality causes different cross sections and different volumes per length unit within the cylinder. Hence, the determination of the measuring volume by using a main inside diameter an increased value of measuring volume will be produced. Using the thousands of data generated for the axial and lateral direction of the cylinder by this new calibration method, the cylinder can be divided into many sectional volumes each based on the measured local geometry. The result of this analysis is

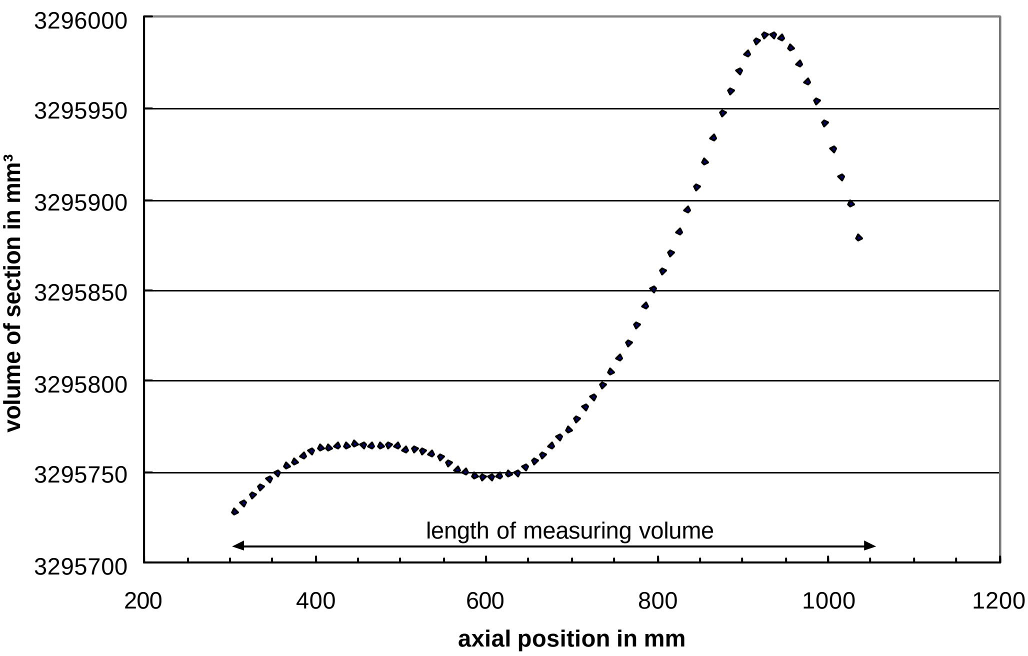


Figure 7: Sectional volumes of the cylinder after dividing the measuring volume into sections of 10 mm length

shown in figure 7. It presents the calculated volumes of these sections each with a length of 10 mm. By integrating these sectional volumes the measuring volume of the pipe prover is calculated to be 250629,710 cm³ ± 4 cm³. This is 0,025 cm³ lower but more precisely evaluated than the measuring volume calculated by a mean inside diameter value.

This slice-by-slice determination delivers a second interesting information about the measured cylinder geometry. The flow tube has a slightly conical form with local fluctuations in volume. In figure 7 a different of 0,007 % can be observed. That means, further studies will have to be carried out to analyze the influence of this form and these fluctuations in the prover geometry, specially on the calibration of flow meters placed behind the pipe prover. The great advantage of the high precision geometrical calibration method is presented here, it is the higher content on information about the object which is under calibration.

Summary

To warrant the low measurement uncertainty of the hydrodynamic test field continuously, the standard measuring devices installed in the test field have to be recalibrated at regular intervals. For the calibration of the pipe prover a new measuring method was developed. The method determines the measuring volume of the pipe prover by a geometrical principle, the technical realization is a world novelty. Comparing of this method with the results generated with the well known gravimetrical method only a different of 0,008 % was measured. This new method allows a lateral scan over the whole length of the measuring volume, a quantified characterization of the flow tube and a more precise determination of the measuring volume.

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