

The Integrated Technical Solutions of Natural Gas Fiscal Measurement in WEPP

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ABSTRACT: On the basis of brief introduction of the West-East Pipeline Project (WEPP), this paper describes the integrated technical solutions of the natural gas fiscal measurements used in WEPP in detail, which include the metering process design, the selection of flow meters and the associated instruments, the initial calibration of the flow meters, and the construction of natural gas flow standard facilities with high pressure and large capacity. The ultrasonic meters and turbine meters are selected, and the skid-mounted complete metering system is provided in each fiscal measurement station. The field check meter has been installed in each skid, and field check method to be used is discussed. The initial calibration results for the ultrasonic meters and turbine meters are presented also, Finally, the gas flow standard facilities consisting of the primary standard, secondary standard, and working standard are briefly introduced, which is designed to carry out full flow range calibrations of flow meters sizing from 50 to 400 mm in diameters.

I. INTRODUCTION

The trunk pipeline of the West –East Pipeline Project (WEPP) starts from the initial pumping station of Lunnan of Xinjiang, and ends at the terminal measurement station of Baihe of Shanghai, with the total length of about 3700 km. The designed pipeline transfer capacity of natural gas will approach up to 120×10^8 Nm³/a with the maximum working pressure of 10 MPa and the pipe diameter of 1016mm. Besides two inlet measurement stations, there are 15 branch fiscal measurement stations and 25 distribution points along the trunk, and the flow rate of the maximum branch output is about 353×10^3 Nm³/h, and the minimum one is 2×10^3 Nm³/h.

The skid-mounted metering systems are provided in each fiscal measurement station, in which there are 2 to 4 ultrasonic meters or turbine meters installed in parallel, and one spare meter among them is used as a check meter which can be switched to its process in series with others. Two connection ports with the associated valves are equipped with for

carrying out meter in-line calibration by a mobile proving system.

For lack of standard gas flow facilities with high pressure and large capacity in China for the moment, the initial calibrations of the flow meters were done in CEESI or Pigsar, then the complete metering skid systems were tested and verified in the fields by China National Station of Petroleum Flow Measurement, the legal metrological verification organization authorized by government.

However, a new natural gas flow standard facility depended on the pipeline is under construction, which includes the primary standard, secondary standard and working standard with the appropriate high pressure and large capacity. The flow facility is designed to provide full range calibrations of flow meters ranging from 50 mm to 400 mm in diameter with the highest working pressure of 10 MPa and maximum actual flow of 12000 m³/h, which will be one important link in the traceable chain of natural gas flow measurements in China. The estimated

expanded uncertainty of the working standard is better than 0.35%, which can meet the needs of calibrations of natural gas meters for custody transfer.

Almost $4 \times 10^8 \text{ Nm}^3$ natural gas has been delivered to the end users along the pipeline from the end of last year with the one-year temporary gas supply from Jingbian station, Shanxi Province, and by the end of this year the whole pipeline construction will be completed with the permanent gas sources from Tarimu oilfield.

II. SKID-MOUNTED METERING SYSTEMS

A. Benefits of Skid Design

In each measurement station one or two separate skid-mounted metering systems are installed, which is dependent on the end users number of natural gas. The benefits of having the manufactures provide the skid metering systems with the gas analyzer subsystems and associated instruments panels with flow computers are as follows:

- 1) The essential components for Total Energy Measurement, i.e. ultrasonic gas flow meter (USM) or gas turbine meter (GTM), flow computer and gas chromatograph are the designated first-class products and are integrated by the qualified engineering resources.
- 2) GC data and water dew point/moisture data are essential for computation in the flow computer for energy measurement.
- 3) The integrated metering systems and analyzer subsystems would be factory tested as one integrated system to ensure the required operation prior to shipment thus minimizing activities on the site and ensuring better project control.
- 4) The integrated configuration of USM, flow computer and gas chromatograph provide "Speed of Sound" verification for each USM transducer path. This is used to validate raw velocity measurements across the chords,

which can help to predict re-calibration requirements.

5) The instruments, electrical cables, control system and station control computer would be compatible and integral to ensure the required functions and reliability.

6) The uniformity would be guaranteed the benefit of the customer for operations and maintenance in the long term.

B. Outline of Metering Skids

The metering skids utilize SENIORSONIC GAS FLOW METERS or GAS TURBINE METERS as the measurement technology. Included are meter run isolation valves, instruments and all the instrumentation accessories mounted in the skid. The skid comes fully assembled with all internal piping, supports, operational access platforms/grating, electrical & instrumentation materials. Electrical tie-in is at the junction boxes provided at the edge of the skid.

Each metering skid has its own metering control panel (MCP) for safe area installation.

The metering control panel is installed with the flow computers and the required accessories.

Each metering skid has its own skid based standalone analyzer house with air-conditioning system, and the associated analyzer. Gas chromatograph with sample handling system is provided with.

Each metering skid has an inlet and outlet header. Where required, additional pipe spools will be provided for connecting the metering skid headers to the respective headers of customer systems.

Meter runs for all metering skids are the same except for the type of meter used and the corresponding upstream and down stream length.

All meter tubes shall have the same pipe internal diameter as the meters. Upstream meter tubes include the following,

* Outer upstream spool of 20 D

* Profiler plate for flow conditioning. This is

sandwiched between the flanges.

* Inner upstream spool of 10 D

Downstream meter tube shall be 5D with the relevant instrument tappings

In the design we have considered the need for meter proving. Cross-over line has been included to allow for meter proving of all meter runs via the first meter run. Ports for the in-line calibration are located downstream of the meter tube.

A less sized metering pipeline is installed in the metering skid at the stations in which it is possible to appear less flow rate in normal process or at the primary stages of the pipeline commissioning.

The 18 metering skids are divided into two types, one is equipped with the gas ultrasonic meters sizing from 150mm to 300mm, and another with the gas turbine meters sizing from 50mm to 150mm. Through competing the bids, Emerson Process Management became the supplier of 10 metering skids with Daniel Senior Sonic 4-Path Ultrasonic Flow Meters, and Elster the supplier of 8 metering skids with Elster G160 to G650 Turbine Flow Meters.

The process schematic diagram of the typical metering system is shown in Fig.1.

III. INITIAL CALIBRATION OF FLOWMETERS

A. Necessity of Flow Meter Calibrations

In the new edition of AGA 9# Report, it is recommended that gas flow meters should be calibrated under or near their operating conditions as possible, which looks like one developing tendency for the calibration technology of natural gas meters. What kind of method is used to calibrate natural gas meters depends on the uncertainty of metering system, the type of calibrated meters, the standard facilities possible to select, and the calibration costs etc. However, the flow calibration under or near meter's operating conditions with the actual medium shall be first

recommended to verify the fiscal meters of natural gas in the metrological meaning.

According to the relative law and regulations in China, the flow meters for fiscal metering shall be forced to be calibrated or verified at regular intervals. In order to assure the metering accuracy and fiscal fairness for the trade parties, the measurement results of natural gas flow shall be traceable to the standard values of flow rate reproduced by the measurement standards of natural gas flow.

However, now it is obvious that the existing gas flow standard facilities in China, whether the pressure rating or maximum flow scale, cannot meet the calibration need of fiscal metering meters used in the West-East Pipeline. In consideration of this kind of condition, China metrological executives made the special permission that the initial calibrations of the ultrasonic meters were done in CEESI, and turbine meters in Pigsar, under the technical supervision of China National Station of Petroleum Flow Measurement, and National Institute of Metrology.

Recent improvements in third party flow calibration facilities have confirmed the some flow meter is capable of performing at low velocities, often allowing a single meter to be used where multiple meters used to be required to achieve the required turndown. Further enhancing this low flow capability, the meter can be calibrated using a multi-point linearization. Rather than a single k-factor used to shift the flow curve up or down or more recent three point polynomial corrections which can apply some additional correction to the minimum and maximum flow, the multi-point linearization allows each flow point taken during calibration to be corrected to zero offset, leaving the meter uncertainty equal to the uncertainty of the calibration facility without further additional uncertainty added for the meter.

B. Calibration Results of Ultrasonic Meters

Flow Calibrations on the ultrasonic meters were at CEESI, Garner, IA, for 7 points + 1 verification point (repeatability) after dry calibration, with the flowing gas velocities of 1 to 26 m/s. Meter adjustment would be performed in accordance with AGA NO.9, Section 6.4.1 (Paragraph A), using a "smart algorithm" error correction method. The calibration pressure and temperature are about 7.3MPa and 20 °C, which are close to the actual operating conditions of the meters. The "as-found" results prior to any adjustment of 25 ultrasonic meters have shown that essentially most of the "as-found" data fall within $\pm 0.5\%$ lower than $\pm 0.7\%$ required by AGA NO.9. All of the data are within $\pm 0.75\%$ required for the natural gas fiscal measurement systems with Class A level according to China Standard GB/T 18603 – 2001 "Technical Requirements of Measuring Systems for Natural Gas". From the "as-found" results it is clear that the flow measurement error for each meter has been greatly reduced, and the metering performance of each meter is better than $\pm 0.2\%$ in its full calibration range. Fig. 2 is an example of a DN 250 mm Ultrasonic meter's calibration results with the serial number 03-110136. The meter's "as-found" results prior to any adjustment at seven flow points are below the zero line, but the error values are smaller than 0.3%. The verification point data become to 0.092% much better than its original value of -0.29% after the multi-point adjustment.

C. Calibration Results of Turbine Meters

Flow calibrations of turbine meters were made in Pigsar with 7 calibration points. The meters were calibrated in full scale, and meter factors for each flow point were supplied for the adjustments through calibration. The calibration pressure is about 5.0MPa, which is the highest working pressure in Pigsar, and meets the technical requirement that the actual operating pressure of turbine meters

should be less than two times of its calibrating pressure according to the related Europe Standard. The calibration temperature is about 15 °C.

The calibration results of these 20 meters have shown that all of the test points data higher than the transit flow rate fall within $\pm 0.5\%$, and some data points at the lower flow rates fall within $\pm 0.7\%$ requirement. The calibrations were done at the points of 5%-100% maximum flow rate, and the meter factor and its repeatability at each calibration point are calculated and presented.

IV. FIELD CHECK AND IN-LINE CALIBRATION

A. Field Check Considerations

To ensure the reliable operating of the metering system, each metering skid is designed at least one meter run as standby line, and generally it is the meter in the first meter run. There is a connecting pipeline between the two streams, which is used to switch the process for checking any other meters by the flow meter in the first meter run. In the case of any possible deviation to be aware in the operating meter, the relative valves can change the stream to pass through the meter under suspicion and first meter simultaneously for comparing and checking. The main purpose of the field check is to find the possible irregular metering results and the unacceptable deviations of meter performance in the routine measurement operations in time. The keys in this kind of comparison and check are to develop a scientific and reasonable evaluation method, to establish the abundant operational history data base of meters. The check meter should have even more calibration datum and good repeatability and long-term stability. The statistical control method may be used in this kind of measurement process control.

The natural gas output in each metering

station along the pipeline are much smaller than its normal value at present, and the flow meters are operating in the very low flow rate. So the actual field check work has not been performed yet, and the related studying work is going on still.

B. In-line Calibration in Future

When the natural gas flow meter is calibrated under or near its operating conditions, the influences of physical parameters' and operating conditions' changes on the meter can be corrected and the meter's accuracy can be improved. The operating conditions of flow meters can influence their performances, one of the most direct influences due to the changes of operating pressure or temperature is the cavity change of a meter spool, and the indirect influences are caused by the changes of viscosity and density of the medium due to the changes of operating conditions.

For example, when an ultrasonic meter is used to measure natural gas, the results of the flow measurement will be influenced by the changes of pressure or temperature. The influences shall be seriously considered when the pressure change is great or the metering accuracy is high.

To carry out the in-line calibration, inlet and outlet connection ports are installed in each metering skid, and located downstream of the meter to be calibrated. For each meter one cross-over line has been included to allow for meter proving of all meter runs via the first meter run (e.g. check meter run). A truck mounted mobile calibration system has been made to order for the purpose.

The mobile calibration system has two turbine meters with different size in parallel as master meters, and one ultrasonic meter as reference meter. A gas chromatograph with sample handling system and calibration gas system is installed on the truck. The two true seal valves and flow control valves are in the outlet ends, and two 6 m long flexible hoses with different

adapters are provided with, which is convenient for connecting with the ports in the metering skids. One data acquisition and control system is equipped, and one industrial PC is used to do data collections and calculations, a laptop computer used to supervise and diagnose the system.

The mobile system's maximum actual flow is 8000 m³/h so that it is intended for calibrating up to 300 mm ultrasonic gas meters. Its estimated flow measurement uncertainty is better than $\pm 0.40\%$, which should be verified after repeatedly lab and field tests. Fig. 3 is the skeleton layout of the mobile calibration system.

V. FLOW STANDARD FACILITY TO BE BUILT

With the constructions of the West to East Pipeline and other important pipeline projects, the numbers of the metering stations for custody transfer rapidly increase, more and more gas flow meters with high pressure and large capacity are used in the stations. Under this kind of new situation, the new requirements for the natural gas flow traceability chain are put forward, especially for the gas flow standards with high pressure and high flow.

Through the feasibility study and the plan discussions, the preliminary and detail designs of the gas flow facility have been finished, and the project construction is in progress now. The facility location is close to Nanjing in Jiangsu province, connected together with Longtan distribution station, the construction of which will be finished by end of 2004. The station has a very suitable operating condition, where the trunk and branch of the pipeline with different working pressure can be used to discharge natural gas. The facility, with the working pressure of about 7.5MPa and the maximum flow of 12000m³/h, can calibrate the flow meters up to 400mm size. It is mainly

used to calibrate the fiscal metering flow meters at full scale.

(1) The primary standard

The main purpose to build the primary standard in the facility is to calibrate master meters used in the secondary standard under their operating pressure of 7.5MPa to ensure the exact same pressure during calibrating and operating. The secondary standard consists of a group of critical nozzles with the measuring uncertainty of up to 0.1%, and flow of the biggest nozzle is about 450m³/h.

The m-t method is finally selected as the primary standard, the main reason of which is that the m-t method has some advantages, such as simple working principle, easy traceability, higher accuracy, and more abundant operating experience. When the maximum flow rate is 450m³/h and gas collecting time is 60s, the weighing vessel volume is about 10m³. Under the working pressures of 4.0MPa or 7.0MPa, the corresponding net mass to be scaled is about 20kg or 540kg. After considering the other factors, the measuring uncertainty of 0.1% can be achieved for the primary standard if the resolution of weighing scale is better than 10g. Fig. 4 is the schematic diagram of the primary standard system.

(2) The secondary standard

The secondary standard uses twelve nozzles with different throat diameters as master meters, and is installed between the primary standard and working standard. Simultaneously, the nozzles can isolate the influence on the flow caused by pressure changes in the weighing vessel. The group of nozzles is used to directly calibrate or correct the reference turbine meters in the working standard. The combined flow range of the different nozzles is 8 m³/h to 3160 m³/h, which can cover with the range of the maximum reference turbine meters which have a flow range of 10m³/h to 1600 m³/h. Because nozzle

has not moveable part and can steady operate for long time, it is an ideal master meter used in the secondary standard.

Fig. 5 is the schematic diagram of the secondary standard and working standard system.

(3) The working standard

The working standard is made up eleven turbine meters with different sizes ranging from 50mm to 200mm in diameter. The maximum flow of a 200mm turbine meter is 1600 m³/h. The highest flow of the working standard is 12000 m³/h measured by the eleven turbine meters installed in parallel, and the operating pressure is from 4.5 MPa to 7.5MPa. The flow measurement uncertainty of the working standard is better than 0.25%, which is allowed to calibrate the fiscal measurement meters with the accuracy of 0.5% or below. Turbine meter has high sensitivity, good repeatability and wide flow range so that it is a suitable master meter in the working standard with high pressure and high flow.

Two ultrasonic meters are installed in the downstream of the master turbines as the check meters used to monitor the metrological performances of the working standard. Ultrasonic flow meter has better self-diagnostic function, which has been used at CEESI and TCC as a check meter successfully.

VI. CONCLUSIONS

1 The ultrasonic meters and turbine meters are selected as the natural gas fiscal measurement flow meters in WEPP, and the skid-mounted complete metering system is provided in each fiscal measurement station. The essential components for Total Energy Measurement, i.e. ultrasonic gas flow meter (USM) or gas turbine meter (GTM), flow computer and gas chromatograph are the designated first-class products and are integrated by the qualified engineering

resources.

2 The initial calibrations of the ultrasonic meters and turbine meters were performed in CEESI or Pigsar respectively. The flow measurement error for each meter has been greatly reduced through the multi-point linearization, and the metering performance of each meter is better than $\pm 0.2\%$ in its full calibration range.

3 The field check meter has been installed in each skid, and the corresponding check and comparison method is studying. To carry out the in-line calibrations of flow meters in future, a truck mounted mobile calibration system has been made to order for the purpose.

4 The West-East Pipeline Project provides an opportunity to set up the gas flow standard facility. The flow standard facility under construction includes the primary standard, secondary standard and working standard, and is designed to provide full range calibrations of flow meters ranging from 50 mm to 400 mm in diameter with the working

pressure of 7.5MPa or lower and maximum actual flow of 12000 m³/h.

The estimated expanded uncertainty of the working standard is better than 0.5%, which can meet the needs of calibrations of natural gas meters for custody transfer now and in the future.

REFERENCES

Zheng Qi and Guo Liang, The Natural Gas Flow Standard Facility with High Pressure and Large Capacity ---The New Needs of Natural Gas Industry in China, in Proceedings of International Symposium on Metrology and Energy Measurement, October 2003, Beijing, China.

Zheng Qi, Traceability of Natural Gas Flow Measurement in China, in Proceedings of the 9th FLOMEKO, June 1998, Lund, Sweden.

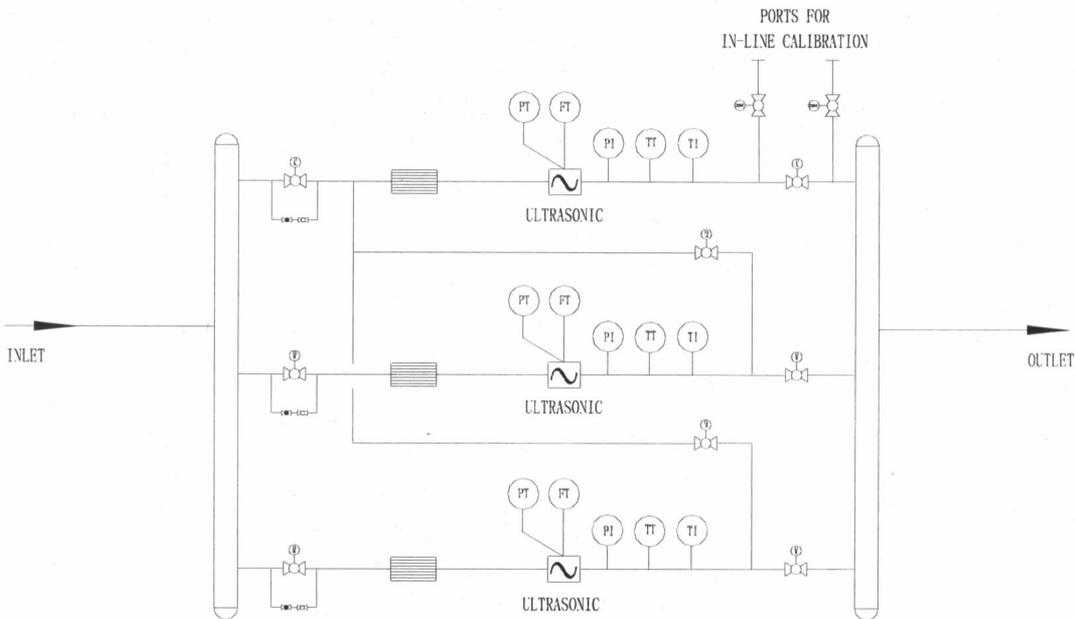


Fig. 1 Process schematic diagram of the typical metering skid

CEESI, Iowa Flow Calibration

| Data Point | Calibration Factor | Flow Rate ft ³ /hr Prover | Flow Rate ft ³ /hr Meter | Flow Rate m ³ /hr Prover | Flow Rate m ³ /hr Meter | Velocity m/sec V _p | Velocity ft/sec V _p | Velocity m/sec V _m | Velocity of ft/sec V _m | As Found error % | As Left error % | Verification Results % |
|------------|--------------------|--|---|---|--|-------------------------------------|--------------------------------------|-------------------------------------|---|---------------------|--------------------|---------------------------|
| 1 | 1.002300 | 182803 | 182429 | 4810.07 | 4599.49 | 25.177 | 82.801 | 25.119 | 82.411 | -0.23 | 0.00 | |
| 2 | 1.002100 | 129048 | 128775 | 3854.15 | 3648.49 | 19.956 | 65.473 | 19.914 | 65.336 | -0.21 | 0.00 | |
| 3 | 1.002900 | 109644 | 109327 | 3104.77 | 3095.79 | 16.956 | 55.630 | 16.907 | 55.469 | -0.29 | 0.00 | 0.092 |
| 4 | 1.002400 | 70263 | 70095 | 1989.63 | 1984.87 | 10.866 | 35.649 | 10.840 | 35.564 | -0.24 | 0.00 | |
| 5 | 1.002200 | 40939 | 40849 | 1159.25 | 1156.71 | 6.331 | 20.771 | 6.317 | 20.725 | -0.22 | 0.00 | |
| 6 | 1.002800 | 20948 | 20894 | 593.19 | 591.85 | 3.240 | 10.828 | 3.231 | 10.801 | -0.26 | 0.00 | |
| 7 | 1.001900 | 8042 | 8031 | 171.09 | 170.77 | 0.934 | 3.066 | 0.933 | 3.060 | -0.19 | 0.00 | |

Note: Velocity of Prover (V_p) is calculated based upon Prover flow rates from CEESI reference turbine meters.

Linearity (As Found) = ± 0.050 % Linearity = 1/2 Peak-to-Peak of Error Peak-to-Peak Error = 0.100%
 Linearity (As Left) = ± 0.000 % Peak-to-Peak Error = 0.000%

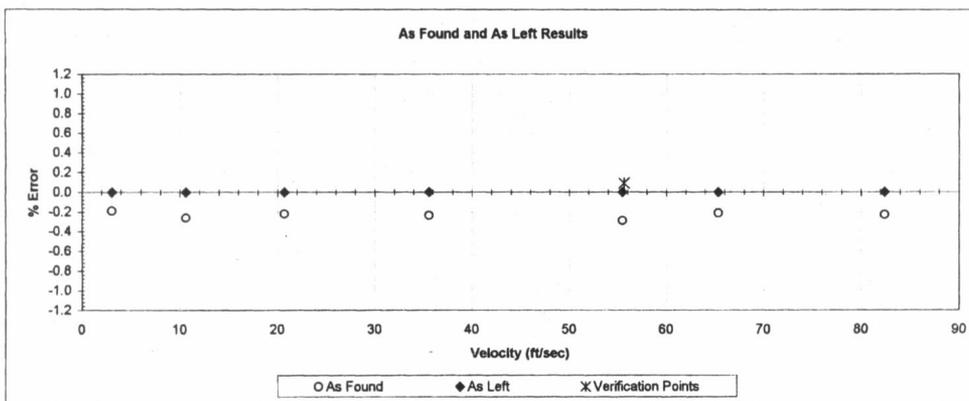
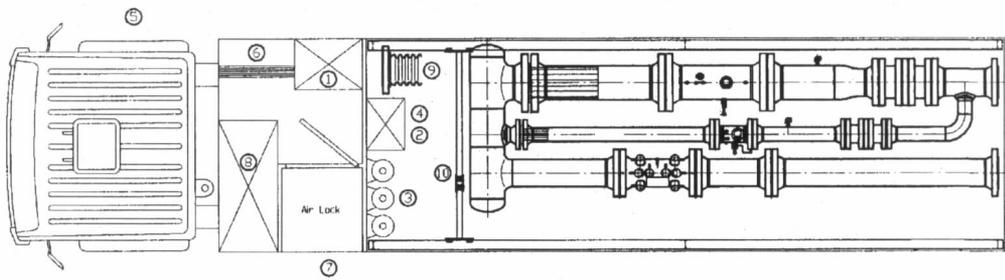


Fig. 2 An example of a DN 250 mm Ultrasonic meter's calibration results



- ① Electronics cabinet
- ② Gas chromatograph ENCAL 200
- ③ Helium & calibration gas bottles
- ④ Sample conditioning set
- ⑤ Main cabin
- ⑥ Airco & heating
- ⑦ Control room
- ⑧ Desk
- ⑨ Flexible connections
- ⑩ Crab type traveling crane

Fig. 3 The skeleton layout of the mobile calibration system

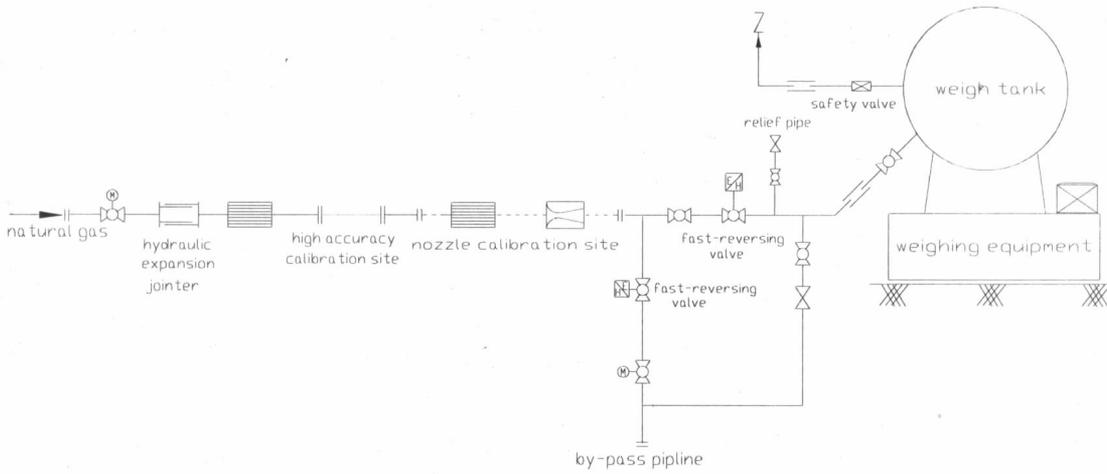


Fig. 4 Schematic diagram of the primary standard system

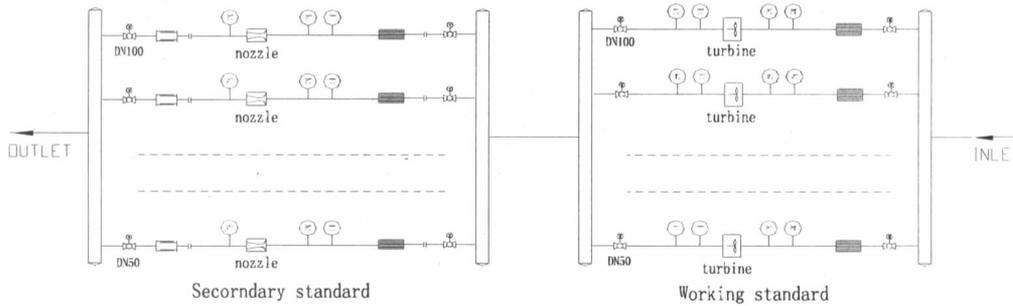


Fig. 5 Schematic diagram of the secondary standard and working standard system