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Research on and Development of Steam Pipeline Creep Real-time Monitoring System Based on Virtual Instrument Technology

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Abstract

With the long influence of high temperature and stress, high temperature & high pressure steam pipeline of a thermal power plant will bring about creep damage or even tube explosion, which heavily threaten its safe operation. Therefore, the timely and accurate measurement of the pipeline creep is vital to the correct estimation of pipeline residual life and the prevention of various security accidents resulted from the pipeline high temperature creep.

This paper put forward a new measurement method, which advanced virtual instrument and data base technology are introduced, and the non-contact precise electronic eddy sensor, converts the measurement of pipeline creep into high precise micro-displacement under the high temperature circumstance, and so completes the non-contact nondestructive examination. The test result is filed in history data base; an analysis and estimation are made on the pipeline residual life and a real-time supervisory information system is run by the LAN interface in Plant Level. It is of great practical exploration with the application of the virtual instrument technology to the Plant comprehensive supervisory information system, which has a good popularized future.

Key words: virtual instrument; steam pipeline; creep; real-time monitoring; nondestructive examination

1. Introduction

With the long influence of high temperature and stress, high temperature & high pressure steam pipeline of a thermal power plant will have creep damage or chronic plastic deformation, or even tube explosion, which heavily threaten its safe operation. Therefore, effective metallic technology monitoring is required for pressure-bearing metallic components in operation temperature no lower than 450℃, such as the high temperature steam pipeline. Via examination and diagnosis of the monitored components adopting advanced online monitoring and diagnosis technology, creep measurement and data analysis can be made for a timely and accurate understanding and diagnosis of the pipeline creep deformation and damage in the monitored metallic components. The timely understanding of the creep rules can help prevent various accidents resulted from metallic high temperature creep damage, decrease the number of times for non-planned operation shutdown, increase the stability of safe operation for the equipment, prolong the lifespan of the equipment, and create more economic benefits and social benefits.

Currently, the measurement of the steam pipeline creep is carried out mostly with special micrometers during the maintenance and repair period (which has greater manual error, lower reliability, inability to acquire the reference data in time so as to affect the decision-making), or with parts of pipeline as samples for microscopic, magnetic and acoustic tests (ultrasonic estimation) so as to make a judgment of material creep damage. These methods are insufficient in manual record, more workload, high cost and long test period.

This paper puts forward a new measurement method, which adopts the non-contact precise eddy current sensor to convert the measurement of pipeline creep into high precision micro-displacement under the high temperature circumstance, thus realizing the non-contact nondestructive examination. With the help of computer technology and online monitoring technology, creep measurement and data analysis are made regularly of the creep measurement section in order to get a timely understanding of the creep in pipeline in operation to provide reliable reference for correct analysis and estimation for the pipeline residual lifespan.

2. Research methods and design principle

The online monitoring of high temperature & high pressure steam pipeline refers to the high precision micro-displacement measurement in high temperature environment. With no identical or similar testing systems available domestically for reference, it is quite difficult to develop. Based on the consultation of a great number of related literature and resources at home and abroad as well as repetitive argumentation, non-contact precise eddy current sensor is adopted to convert the measurement of pipeline creep into the measurement of high precision micro-displacement in high temperature environment, thus realizing non-contact nondestructive examination with a precision as high as ten microns.

2.1 The selection of sensor

Since the creep monitoring component operates in a temperature no lower than 450℃, stress and strain gauge was used in the past. However, commonly-used stress and strain gauges operate in normal temperature, and it is costly to adopt temperature-resistant strain gauges, which is inconvenient for setting systematic monitor points on a large scale, and which requires a re-calibration for the strain gauges with a very strict requirement for experiment conditions and equipment. In addition, the characteristic of the strain gauge is highly disagreeable with severe data drift in the long term and a hard-to-achieve precision. What’s more, the sticking material will easily age and fall off in high temperature. In some cases, solid pressure sensor was also adopted, but it has a one-way deformation with inability to examine the deformation in the opposite direction. In addition, the pressure sensor will easily become exhausted with data drift in the long term, a low precision, and unsatisfactory application effect, which make it an inappropriate option.

Non-contact measurement can avoid the temperature influence of contact measurement, thus being a good alternative. However, in this type of sensors, such as linear matrix CCD video camera or laser displacement sensor, in spite of its high precision and minor temperature influence, it is still unsuitable for long monitoring due to the factors of pipeline vibration, costly sensor, short lifespan, and installation restrictions.

This system adopts the non-contact precision eddy current displacement sensor to convert the radial and transverse pipeline deformations into the change in analog voltage signal (as shown in Fig.1). Its resolution ranges from 8μm to 0.1nm, the measurement range from 0.05 mm to 65mm, and the extreme operation temperatures from -196℃ to 538℃. With a high measurement precision, it can measure the deformation in both directions so as to meet the requirement fro precision in this system. In addition, it has a wide range of operation temperature with little influence by the temperature on-the-spot, and appropriate cooling measures can be taken in the testing equipment if necessary. At the same time, this sensor has a stable chemical performance with no influence by medium such as oil taint. With a strong anti-interference from magnetic field, it can be used in devices producing a magnetic field, such as in a generator. Its installation, maintenance and replacement can be done conveniently.

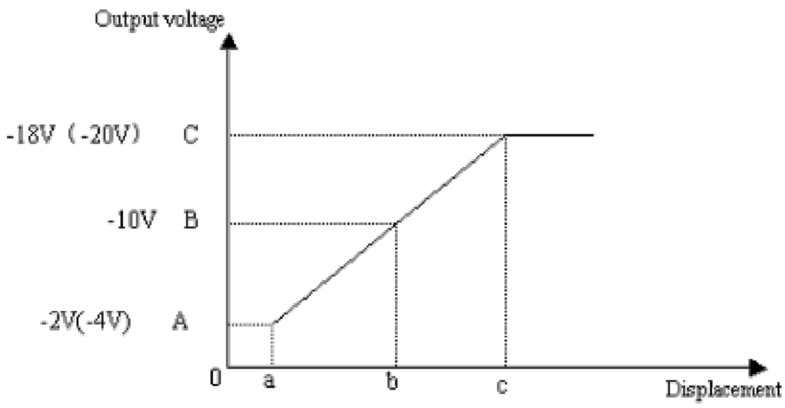

Fig.1 Displacement versus output voltage curve

2.2 Design of the general system scheme

A designated measurement device is designed to act three groups of precision eddy current displacement sensors on one creep measurement section (radial creep and transverse creep) on the surface of the elliptical monitor curving pipeline. 3 groups of measurement points are required for one measurement section (monitor point), and two eddy current sensors for one group. The radial and transverse deformations of the pipeline produced in high temperature and high pressure are converted into slight changes in electric signal, which is filtered, amplified and transmitted to be turned into digital quantity by data acquisition system. This digital quantity is delivered via communication interface to the computer for further data processing (digital filtering, data processing in different pipeline operation conditions and in abnormal situations, the calculation of creep parameter, creep deformation quantity graph, etc.), thus producing various parameters for the curving pipeline's absolute and relative creep deformation quantities, which are displayed and filed in background database. Refer to Fig.2 for the general system design block diagram.

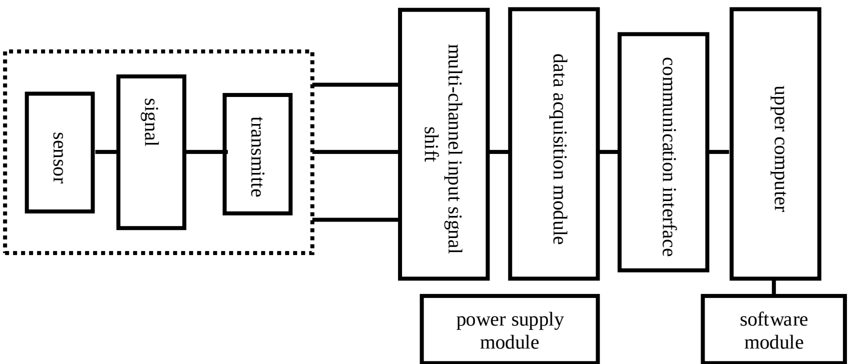

Fig.2 Block diagram for the general system design

Due to a high requirement for the measurement precision and severe environment, the system should give full consideration to the effects of electromagnetic interference, cold-and-warm environment, and vibration noise in the design of hardware and software.

3. System implementation

3.1 Hardware design

The micro-displacement (deformation) produced in each monitor point is converted via measurement equipment into analog electric voltage, which is converted into digital quantity by data acquisition converter. The digital quantity is then delivered via communication interfaces RS485 and RS232C to the computer for further digital filtering, nonlinear adjustment and scale conversion, thus producing various creep parameters and identifying or giving alarm about some dangerous pipeline states. At the same time, the test results will be filed in history database to analyse and predict the pipeline residual lifespan. It is also connected via LAN interface to the Plant Level real-time monitoring information system in a thermal power plant. Interface RS485 with good augment ability is adopted in data transmission from the monitor points, so it becomes easier to increase creep monitor points as required.

3.1.1 The design of sensor-designated measurement equipment

The designated measurement equipment is used to fix perfectly the precision eddy current displacement sensor to the surface of the elliptical monitor curving pipeline. Since the pipeline deformations in different operation environments may be much greater than the pipeline creep, the acquisition of effective creep signal has much to do with the design of measurement equipment. Therefore, the selected material for the designated testing equipment should be rigid enough to guarantee a small heat expansion. If necessary, corresponding cooling measures can be taken. Refer to Fig.3 for the sketch map for the structure of the designated measurement equipment.

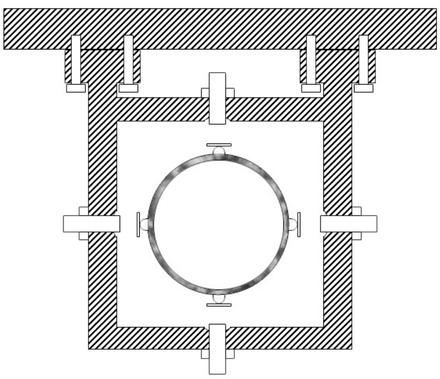

Fig.3 Sketch map for the structure of the designated measurement equipment

3.1.2 The design of signal adjustment module

The deformation perceived by the eddy current probe is output via preamplifier to be an analog voltage signal ranging from −18V to −2V, which needs further amplification by the amplifying circuit and filtering so as to facilitate quantitative processing by the data acquisition converter.

3.1.3 The design of data acquisition module

Multi-channel analog switch is used to connect the three routes of tested signals time-sharing shift to the common data acquisition module. Since the creep precise to a micron is required to be measured, an analog-digital conversion device ADC with high resolution is selected. Since the steam pipeline creep happen at a slow speed in operation, conversion speed may not be taken into consideration in selecting ADC device. Based on all these requirements, an ADC device with 16-digit resolution, a precision of 0.05%, and a sampling rate of 10 times/second is selected to convert the adjusted analog electric voltage into a digital quantity. Under the control of the upper computer, the standard quantity connected is acquired and converted into a digital quantity, which is transmitted to the upper computer via communication interface RS-485 for further processing.

3.2 The design of software

The monitoring software employs virtual instrument development platform LabVIEW under Windows operating system, which is convenient in expansion, good in reuse and interchangeable.

The software in the system performs interface operation on the hardware to acquire the digital quantity of pipeline deformation and to perform further data processing on the digital quantity based on the different pipeline states when the machine units starts, shuts down, and operate normally (including digital filtering, elimination of abnormal data, data processing in different pipeline operation conditions, the calculation of creep parameters, creep deformation quantity graph, etc.). In this way, the parameters of the pipeline's absolute and relative creep deformation quantity are acquired, displayed and filed in background history database. Refer to Fig.4 for the block diagram of the system software structure.

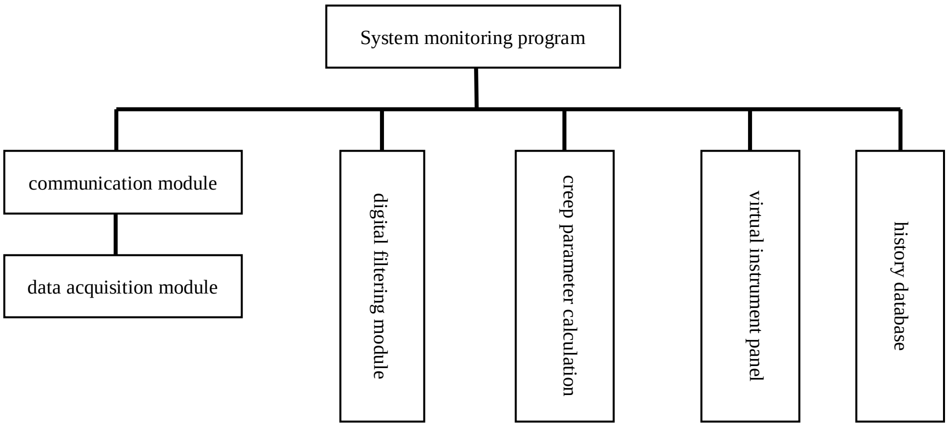

Fig.4 The block diagram for the system software structure

① System monitoring program: monitor the normal operation of the system software and hardware, and perform reasonable arrangement for the operation of the mainframe and the peripheral equipment;

② Data acquisition module and communication module: initialize the data acquisition part in hardware, control the start of shutdown, and transmit the acquired data to the upper mainframe according to related communication protocol.

③ Digital filtering module: use digital filtering module software package to eliminate various interferences introduced into the measurement circuit and measurement environment to acquire effective measurement data;

④ Creep parameter calculation module: program based on the designed formula to calculate, analyse, and display the effective data so as to have a timely understanding of the creep rules in high temperature steam metallic pipeline, thus providing reliable reference for correct analysis and prediction of the pipeline residual lifespan, increasing the reliability of safe operation of the equipment, and prolonging the lifespan of the equipment.

⑤ The interactive panel of the virtual instrument: adopts the virtual instrument software design platform LabVIEW to enter the program in an interaction between human and the computer so as to draw the relative creep deformation quantity versus operation time (ε-t) curve, which can be observed by zooming in the local areas of the curve. Data in different processing stages can be displayed in values, graphs, and forms.

⑥ History database: record automatically the effective data at each monitor point in the operation process as well as the reference data from redundant equipment and at different processing stages into the history database, thus gathering the precious first-hand scientific data. The data can reproduce the real situation on the spot, thus providing data source for further system trouble-shooting in the power plant's comprehensive intelligent monitoring system.

Refer to Fig.5 and Fig.6 for part of the virtual panel

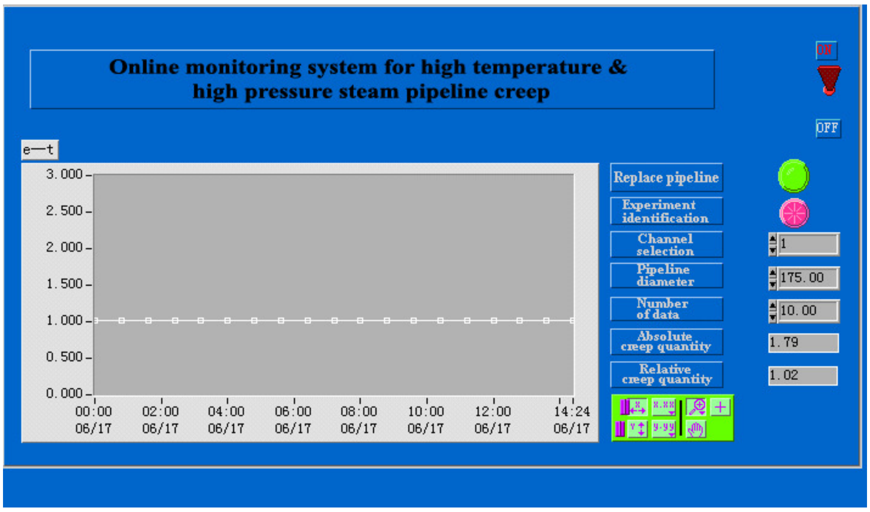

Fig.5 When the relative creep deformation quantity reaches 1%, the system will sound the alarm and suggest an experiment identification.

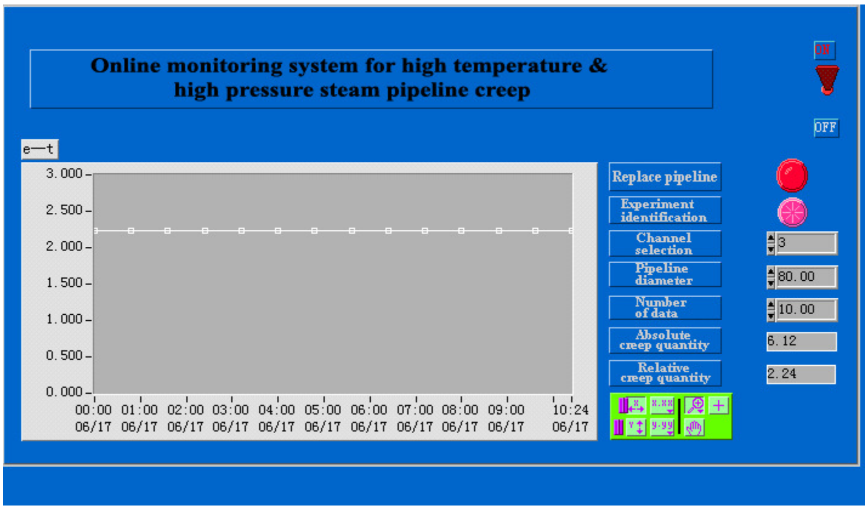

Fig.6 When the relative creep deformation quantity reaches 2%, the system will sound the alarm and suggest replacing the pipeline.

4. Test results

After the design and debugging are done, the system is calibrated and compared to see whether it has met the design requirements. A micrometer precise to micron and the system are adopted at the same time to measure a deformation quantity ΔD (the test results are omitted). From the test data, in the tens digit (the unit is micron), the system has quite a stable reading, which is the same as that in the micrometer.

5. Conclusion

The pipeline creep real-time monitoring system can realize the online real-time monitoring of high temperature & high pressure steam pipeline creep in terms of the absolute creep deformation quantity ΔD and the relative creep deformation quantity ε of the pipeline diameter. It can also draw the relative creep deformation quantity versus operation time (ε-t) curve, estimate the time to enter constant speed creep stage based on the deformation quantity, calculate the creep speed v in creep constant speed stage, and monitor the pipeline creep (experiment will be done for identification if overall relative creep deformation quantity ε reaches 1%, and pipeline will be replaced if overall relative creep deformation quantity ε reaches 2%). On the basis of the test in Materials Research Dept. in Xi'an Thermal Power Research Institute Co., Ltd, the system has realized the long, real-time monitoring of the steam pipeline creep (especially curving pipeline) with a precision of micron. It is of great practical exploration with the application of the virtual instrument technology to the Plant comprehensive monitoring information system, which has a good popularized future.

The system adopts the internationally advanced virtual instrument technology (VI) to improve substantially the modularization, intelligentization, universalness, expansibility, and the advanced level for technical realization. It is of great practical exploration significance with the application of the virtual instrument technology to the Plant comprehensive monitoring information system, which has a good popularization future.

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