Abstract:

JFE Engineering has developed a unique non-destructive stress measuring method using a magnetic anisotropy sensor and various evaluation systems applying this technology. This paper describes the principle of the stress measuring method and the experimental results which demonstrate the usefulness of the method in evaluating the stress levels in linepipes under working conditions for maintenance purposes.

1. Introduction

From the viewpoint of maintenance, the measurement of the stress levels in linepipes is an effective tool for evaluating the safety of a pipeline system. In a structure, stress is generally measured by the strain gauge method, but it is diffcult to measure the stress level in an existing pipeline system using strain gauges without destructive inspection, with accompanying stress relieving work. Moreover, the range of application of this technique is naturally limited because destructive

$$V \quad K \cdot (\sigma_X \quad \sigma_Y) \cdots\cdots\cdots\cdots (2)$$

where, K: A constant determined by excitation conditions, coil conditions, magnetic properties of the material, etc.

Thus, if the proportional constant K (hereinafter referred to as magnetostrictive sensitivity) is known, the difference in stress can be obtained as the output voltage of the magnetic anisotropy sensor.

According to the principle, the output voltage takes the form of a sine wave with a cycle of 180° when the sensor is rotated around the measuring object, and the direction where the output voltage displays its maximum value corresponds to the principal stress direction. Under this condition, if the stress in the measuring object exists in a uniaxial or nearly uniaxial stress feld, an approximate principal stress can be measured.

According to the principle, the stress obtained by a magnetic anisotropy sensor is measured as the absolute stress, i.e., the sum of residual stress component and external stress component.

3. Method of Measuring Bending Stress in Pipe Using Magnetostrictive Method

The magnetostrictive stress measuring method which is based on the principle and features described above was used to develop a system for measuring bending stress in a linepipe.

3.1 Principle of Bending Stress Measurement

The output voltage from the magnetic anisotropy sensor varies in a certain degree owing to the variance in residual stress in the measurement object. Consequently, it is diffcult to estimate the external stress acting on the whole object using a local measurement. The authors therefore devised a stress estimation method called as the cosine curve ftting method, as discussed below.

The system hardware consists of a tracking rail corresponding to the pipe diameter, a scanning head which enables the magnetic anisotropy sensor to scan the pipe while traveling on the rail, and a laptop personal computer for equipment control and analysis of the measured results. The magnetic anisotropy sensor is moved automatically around the circumference of the pipe by the scanning head and measures the stress distribution on the pipe surface. The measured results are analyzed in real time by the personal computer, which displays the magnitude and direction of bending stress.

The magnetostrictive sensitivity changes depending on the distance between the sensor and pipe surface or lift-off. However, the developed system is equipped with an automatic compensation function which detects the actual amount of lift-off and corrects the magnetostrictive sensitivity correspondingly.

Three versions of the system have been developed, GYK-S, -H, and -M types. The GYK-S type is used with small- and medium-diameter coated pipes, PLP pipes, and others with the maximum coating thickness of approximately 6 mm. The GYK-H type is applicable to large-diameter pipes and is used with heavy-coating pipes with coating thickness up to 15 mm, enabling direct measurement on the coating without coating removal.

The measuring time depends on the pipe diameter, but the entire process from measurement through anal-

residual stress in the pipe.

5. Linepipe Safety Evaluation Method

Under practical conditions, various factors limit the locations where stress measurements can be performed on linepipes. For such cases, a combination of direct stress measurement/evaluation by the magnetostrictive method and the finite element method (FEM) calculation is effective. The following presents examples of techniques in which the magnetostrictive method is applied under the actual working conditions:

5.1 Bridge Crossing with Pipe

Linepipes are generally laid underground. However, at a river crossing, the pipe may be constructed as part of a roadway bridge or an exclusive-use linepipe bridge as shown in **Fig. 6**. Although bridge abutments and pier foundations are strong and secure, there are cases in which non-uniform subsidence occurs at the back side of the abutments due to compaction (consolidation) of the ground. In such cases, the linepipe is affected by a bending moment, with the passage through the abutment acting as a fulcrum, generating bending stress in the pipe.

The linepipes constructed on bridges are normally accessible for measurement, as the pipes are left exposed with painting or coating for protection. Therefore, the following method is used in stress evaluations:

(1) At bridge parts ①, ②, and ..., where the pipe is accessible, stress is measured and evaluated directly by the magnetostrictive method.

(2) The amount of subsidence at the back side of the bridge abutment is given by an FEM calculation, and the amount of subsidence at which the stress in the bridge section of the pipe agrees with the measured values in (1) is obtained.

(3) The stress distribution in the linepipe system as a whole is verifed] p tion stribi \ h epiy annn m