Electromagnetic acoustic transducers for non-destructive testing of main pipelines

A V Mikhaylov¹, Yu L Gobov¹, Ya G Smorodinskii² and G S Korzunin³

¹ Senior Researcher, M N Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, Yekaterinburg, Russian Federation, 620137
² Head of Department, M N Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, Yekaterinburg, Russian Federation, 620137
³ Chief Expert Advisor, M N Mikheev Institute of Metal Physics of Ural Branch of Russian Academy of Sciences, Yekaterinburg, Russian Federation, 620137

mikhaylov@imp.uran.ru

Abstract. The article presents the design options for high-performance electromagnetic-acoustic transducers for monitoring pipelines by the waveguide ultrasonic method. Methods for creating large polarizing fields, which make it possible to increase the efficiency of excitation and reception of Lamb and Rayleigh waves in ferromagnets are proposed. The results obtained in this paper can be used in the development of devices for non-destructive testing of trunk pipelines.

1. Introduction

Pipeline transport is the most important and loaded technological facility in Russia. Gas and oil pipelines are subject to a significant influence of both corrosion and fatigue failure; therefore, they require sensitive and reliable methods of non-destructive testing of long steel structures. Testing of these products should be carried out at their locations, which requires the stability of non-destructive testing methods to environmental conditions, the quality of surface preparation, as well as to the testing speed. Thanks to this the method of ultrasonic testing using electromagnetic-acoustic (EMA) transducers has become widespread [1].

Access to the surface of the pipeline is often limited by its size and configuration, so the installation of non-destructive testing means is possible only from one (external or internal) surface of the object. It is advisable to exclude mechanical scanning of its entire surface and use the waveguide echo method of ultrasonic testing. The method is based on non-contact excitation and reception of ultrasonic waves of Lamb, Rayleigh or SH waves propagating through the material of the test object like a waveguide. The main condition for the manifestation of the waveguide effect is the limitedness of the test object in one or two dimensions and the extent in the remaining dimensions.

The main disadvantage of the EMA method compared to contact ultrasound is the need to use magnetizing systems that create strong magnetizing fields as part of the EMA. When developing an EMA for monitoring pipelines, their thickness must be taken into account, since the larger it is, the more difficult it is to magnetize a ferromagnet. The magnitude of the polarizing field directly affects the efficiency of the mutual conversion of electromagnetic and acoustic vibrations, and, therefore, the sensitivity of EMA transducers to defects. Existing devices either have insufficient sensitivity to defects of discontinuity due to the small magnitude of the magnetizing field, or they are massive and
strongly attracted to the surface of a ferromagnetic object. This work is devoted to the development of EMA transducers with increased sensitivity to continuity defects when monitoring the integrity of pipeline transport.

2. Methods
Basically, there are two EMA conversion mechanisms in ferromagnets – electrodynamic and magnetostrictive. To strengthen one of these mechanisms, a tangential or normal polarization field must be applied to the ferromagnetic object (figure 1).

![Figure 1: EMA conversion mechanisms](image)

(a), (b) magnetostrictive; (c), (d) electrodynamic: 1 – the permanent magnet; 2 – pipe wall; 3 – meander coil for exciting/receiving ultrasonic waves; 4 – the direction of the magnetizing field; 5 – alternating magnetic field caused by the coil 3; 6 – pole of the U-shaped magnet.

The maximum efficiency of the magnetostrictive conversion of EMA (tangential magnetization) is achieved at a magnetic field strength of about 300 A/cm. The efficiency of electrodynamic EMA conversion (normal magnetization) increases with increasing applied magnetic field, and with induction above ~1.2 T, the efficiency of conversion with normal magnetization exceeds the maximum possible efficiency of EMA conversion with tangential magnetization [2]. The creation of such polarization fields is possible only with the help of special configuration magnetization systems [3]. Thus, the task of increasing the sensitivity of the EMA method for monitoring pipelines is reduced to the development of magnetizing systems that allow you to create polarizing fields with specified parameters.

3. Results
Creating a normal magnetizing field for EMA converters is advisable to carry out using a magnetizing system with a non-collinear arrangement of permanent magnets. The direction of polarization of each individual magnet is selected based on considerations of maximizing its contribution to the field created in a given region of space (figure 2(a)). Fields from different magnets are superimposed on each other without changing the characteristics of individual magnets, provided that the coercive force by magnetization is taken into account (figure 2(b)).
Figure 2. Directions of polarization of magnets aligned along dipole field lines (a), distribution of magnetic induction of an ideal magnetizing system with optimal directions of polarization of magnets (b).

It is quite difficult to make such a system. Dozens of types of magnets with different directions of polarization and complex mandrels for assembly are needed. By successively reducing the number of elements and averaging the directions of polarization of the magnets in each element, the system shown in Figure 3(a) was obtained, and the dependence of the normal component of induction in a ferromagnet on the distance to the center of the magnetizing system is shown by the curve in figure 3(b).

Figure 3. The distribution of magnetic induction of a simplified magnetizing system with optimal directions of polarization of magnets.

An experimental verification of the magnetization system, calculated by the principle of noncollinear arrangement of permanent magnets, showed that it creates magnetic induction in the 50×50 mm working zone in excess of 1.7 T. Such a system was manufactured, the normal component of the magnetic field induction in the working area of a real system reaches 1.3 T, which is in good agreement with the calculations. The use of such a system as a magnetizing system of EMA converters allows to increase the signal-to-noise ratio by at least 4 times (2 times with radiation and 2 times with reception) and significantly increase the sensitivity of EMA converters.

The maximum efficiency with tangential magnetization (magnetostrictive EMA conversion) is achieved at a magnetic field strength of about 300 A/cm. To obtain such a field value with the minimum weight and size characteristics of the magnetization system, pulse magnetization technology can be used. Current instruments use a normal pulsed polarizing field. In this case, eddy currents interfere with the creation of the required magnetic field in the material of the test object. With a parallel pulsed polarizing field, eddy currents, on the contrary, help to magnetize the surface layer of the test object to saturation and create the necessary amplitude of the polarizing field. The easiest way
to create a pulsed tangential polarizing field is using a U-shaped electromagnet, in the winding of which a pulsed current is supplied.

It is believed that in parallel magnetization with a U-shaped attached electromagnet, the thickness of a ferromagnetic object plays an important role: the larger it is, the more difficult it is to create the required magnetic field due to the spreading of the magnetic flux deep into the ferromagnet. When pulsed magnetization occurs in the object, eddy currents “push” the magnetic flux to its surface, so there is no need to “magnetize” a ferromagnet over its entire thickness, which is a significant advantage of using tangential pulsed magnetization. In addition, you a short magnetization pulse can be used, which will significantly reduce the energy consumption of a pulsed electromagnet, since the shorter the magnetization pulse duration is, the smaller is the depth of the skin layer and the easier it is to create the required magnetic field in it.

The geometric and electrical parameters of the pulsed magnetizing U-shaped system should be calculated and optimized taking into account the set field value, the sizes of the coils of the EMA transducer for the exciting required waves, as well as the gap between the pole of the electromagnet and the surface of the ferromagnet. For these purposes, one can use the expressions obtained in [4] when calculating the magnetic circuit using analogues of Ohm and Kirchhoff laws. A model of a magnetizing system with magnetic flux distribution is shown in Fig. 4a, the appearance of the calculated and fabricated pulsed electromagnet for excitation of Lamb and Rayleigh waves on a ferromagnetic plate (scan of the pipeline) in figure 4b.

![Model (a) and the appearance (b) of U-shaped pulse magnetizing system.](image)

Figure 4. Model (a) and the appearance (b) of U-shaped pulse magnetizing system.

Designed U-shaped pulse magnetizing system can be used in the EMA transducers and during the scanning non-destructive testing. The gap between the poles of the electromagnet and the ferromagnetic surface can thus reach 1.5 mm.

4. Conclusion

The proposed magnetizing systems make it possible to increase the sensitivity of EMA converters, as well as significantly reduce their mass and the force of attraction to the surface of a tested gas and oil pipeline.

The work was performed in accordance with the theme «Diagnostics» No. AAAA-A18-118020690196-3.

References

[1] Murav'ev V V, Murav'eva O V, Platunov A V and Zlobin D V 2012 Russian J. of NDT 48 447
[2] Aleshin N P, Gobov Yu L., Mikhailov A V., Smorodinskii Ya G. and Syrkin M M 2014 Russian J. of NDT 50 133
[3] Samokрутов A A, Alehin S G, Shevaldykin V G, Bobrov V T and Bobrov S V 2014 Kontrol'. Diagnostika [Testing . diagnostics] 12 22
[4] Mikhailov A V, Gobov Yu L, Smorodinskii Ya G and Shherbinin S V 2015 Russian J. of NDT 51 467

4