

LENGTH MEASUREMENTS OF THIN METAL TUBES AND RODS

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Abstract: Methods and devices for on-line measurements of produced thin metal tubes and rods are proposed. They are based on the use of a monitored article as a conductor of synthesised TEM-transmission line section. Resonance frequency of electromagnetic oscillations of such line section and period of pulses sequence excited in it serve as informative parameters of the designed length sensors.

Keywords: thin metal tubes and rods, length, measurement

1 INTRODUCTION

Economy of metal, decrease of metal capacity are tasks of great importance under production of metal elongated articles (tubes, rods, etc.). It is effectively provided in particular by the use of contactless methods and means for measurements of geometrical quantities (length, cross-section dimensions) of produced articles. Among known measurement methods attention should be put to radiofrequency and microwave techniques that are successfully applied for measurements of many nonelectrical quantities [1,2]

2 LENGTH MEASUREMENT PRINCIPLES

Design principles for contactless length measurement of produced elongated thin articles like steel tubes and rods with small and middle-size diameter, rolled ferrous and non-ferrous metals, etc. are considered. Cross-sections of such articles are 10-20 times smaller than their lengths. The proposed principles can be used for instance under the production of tubes for measurements of their lengths and determination of summary length of tubes being packed. Length of a metal article is important technological parameter that determines quality, metal capacity and prize of this article.

A metal article with the length l to be measured is placed over grounded metal screen being isolated from it. For this purpose can be used both separately located dielectric supports and continuous dielectric coating on the screen at the measurement section (table). In turn the screen can represent metal plane or hollow cylinder with longitudinal slot. Thus *TEM* -line section with open ends is formed. Here a monitoring article (tube, rod, et al) serves as one of conductors of such a line section. Near one end of an article between it and the screen are placed elements for excitation of electromagnetic oscillations and for reception of signals. Exciting and receiving elements are connected correspondingly to the output and input of the continuous wave or pulse generator. Two methods may be suggested for length determination of a metal article according to used informative parameters of designed length sensors.

2.1 Resonance frequency measurements

According to the first measurement method resonance frequency f of such synthesised *TEM* -line section is measured. Electromagnetic oscillations in such a line section are excited by high frequency oscillator using exciting element. Dependence of f on measured length l of an article is expressed by the following relationship:

$$f = \frac{cn}{2l} \quad (1)$$

In this formula c is the light velocity, $n=1,2,\dots$ is number of an excited harmonic of TEM -oscillations. In (1) are not taken into account the influence on f of coupling elements and environment factors.

For real conditions $f(l)$ may be written so:

$$f = \frac{cn}{2l\sqrt{\epsilon m \left(1 + \frac{C_c}{C_l}\right)}} \quad (2)$$

Here C_c and C_l are capacitances of coupling element at the line end and of the line per unit length, correspondently; ϵ and m are dielectric permittivity and magnetic permeability of the environment near the line. Presence of dielectric supports for a monitored article has also some influence on the value of C_l .

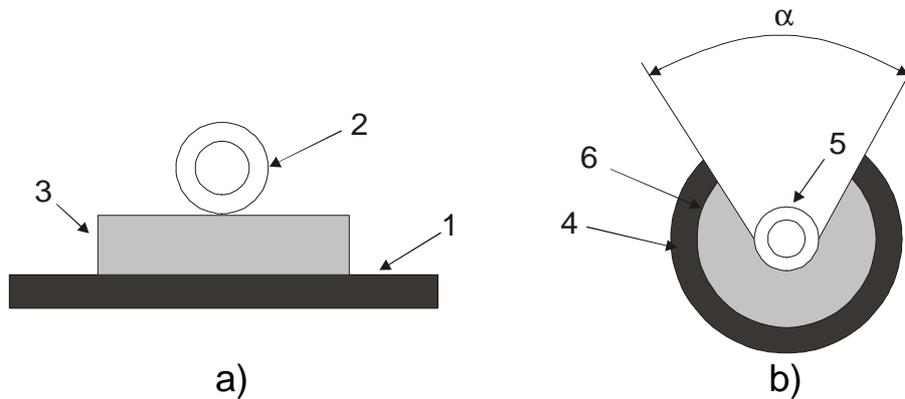


Figure 1. Cross-sections of resonance length sensors

Two such designed radiofrequency (RF) resonance sensors (cross-sections) are shown in Fig.1. The first sensor is made with flat screen 1; a monitored article 2 is placed over this screen on dielectric supports 3 (Fig. 1a). The second sensor has cylinder screen 4 and longitudinal slot for introducing a monitored article 5 into the space and taking it off from this space. An article is placed on dielectric supports 6 during measuring periods (Fig. 1b).

Choice of cylinder-like form of a screen is motivated by the following. In some cases functioning of such a length metering device is the source of disturbances for nearby placed radio installations. These disturbances appear because of weak high frequency electromagnetic radiation from open two-wire line that is formed by an elongated monitored metal article and grounded metal screen. In turn, parameters of such open line are influenced by environment disturbances. For significant decrease of possible mutual influence of the sensor and surrounding objects may be used sensor construction having screen made by hollow cylinder with longitudinal slot. Through such a slot a metal article is introduced into the screen on dielectric supports along the axis and is removed from it after finishing the measurement process period. Coaxial (not open two-wire) TEM -transmission line is connected with electronic unit of the device by coupling element (transmitting-receiving probe) that is introduced into the space between the screen and the monitored article.

The screens of both sensors have elongated forms, their lengths some exceed maximal length value of an article. Coupling elements (for exciting electromagnetic oscillations in each resonator sensor and receiving informative signals) are placed at one of the ends of an article and a screen. Experiments for optimisation of basic construction characteristics of such resonance sensors were undertaken that allowed choose dimensions of screen, slot in it and position of coupling elements relative to a monitored article. So, optimal value of screen angle $\alpha = 60^\circ$ provides non-sensitivity of sensor resonance frequency versus an article vertical position at the location of $0,6\div 1$ diameter value relative to the lowest screen point.

In Fig. 2 are shown calculated curve $f(l)$ for ideal line section (line 1) and experimental curves received for considered real line sections with line supports as thin dielectric threads (line 2) and as dielectric supports (line 3). These experimental curves are shown as frequency deviations $\Delta f/f$ (in percents) from the ideal curve. It follows from Fig. 2 that for real line sections frequency ranges are $6\div 8$

percents decreased with simultaneous presence of local frequency non-uniformities at places of dielectric supports.

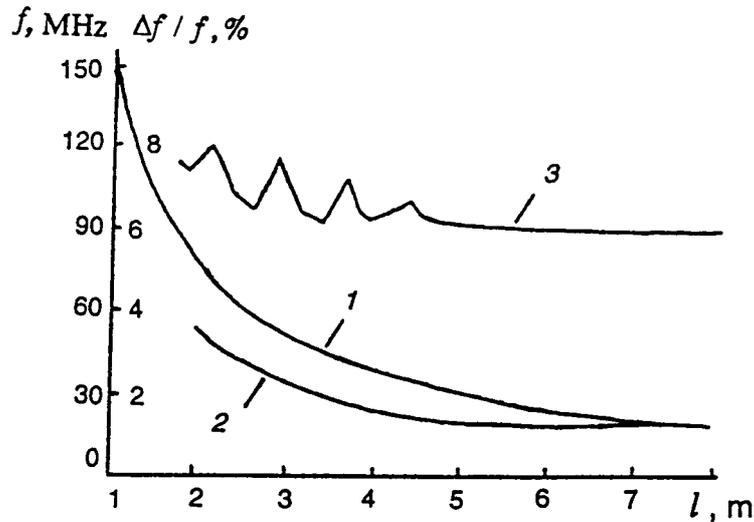


Figure 2. Output characteristics of synthesised sensors

There are also several resonance scale sensors for rough length determination realised on the base of coaxial line sections. Their resonance frequencies correspond to length values of articles that are divisible to meters. A monitored article is coupled by receiving element with processing unit of the device.

Electromagnetic oscillations are excited from sweep generator in both synthesised line section and resonance scale sensors. For one modulation period scale sensors are excited in turn at their resonance frequencies resulting in scale sequence of pulses. Here every pulse corresponds to a certain length value of a monitored metal article that is equal to a whole number of meters. Resonance frequency of the synthesised *TEM*-line section is between two certain scale pulses depending on real length of a tube or rod. Then after data processing in the processing unit pulses corresponding to the whole numbers of an article length come to the counter of rough length value. It is also foreseen more accurate length determination by counting parts of meters in scale sensors. For this purpose introduction of pulses with stable frequency into the scale sequence of pulses is used. In processing unit of the device measured length l is determined according to the following relationship:

$$l = L - MQ - mq \quad (3)$$

Here L is the length equal to the maximum value of an article length; $M = 1 m$ - unit for counting pulses of rough length determination; Q and q are numbers of pulses corresponding to rough and accurate counts for length determination of an article. Experiments showed that absolute error is not more than 20 mm for articles with lengths 1,5 - 9 m and diameters 6 - 18 mm.

2.2 Period of pulse sequence measurements

If the second suggested measurement method is realised then pulse signals are excited in the section of *TEM*-line formed by a monitored elongated article 1 and the screen 2 (Fig. 3). Separately placed dielectric supports 3 or dielectric coating on the screen 2 serve for isolation of conductors 1 and 2 of such *TEM*-transmission line. Screen 2 may also have cylinder-like form with longitudinal slot. Near one end of an article (tube, rod, etc.) 1 element 4 for excitation of oscillations and receiving element 5 are placed. Coupling elements 4 and 5 are connected to the output and input of pulse generator 6, correspondently. Unit 7 for processing of signals is also connected to the output of the pulse generator 6. Signals from output of the unit 7 come to one input of the register 9. Its second input is connected with the unit 8 for corrections of measuring results according to the diameter range of monitored articles.

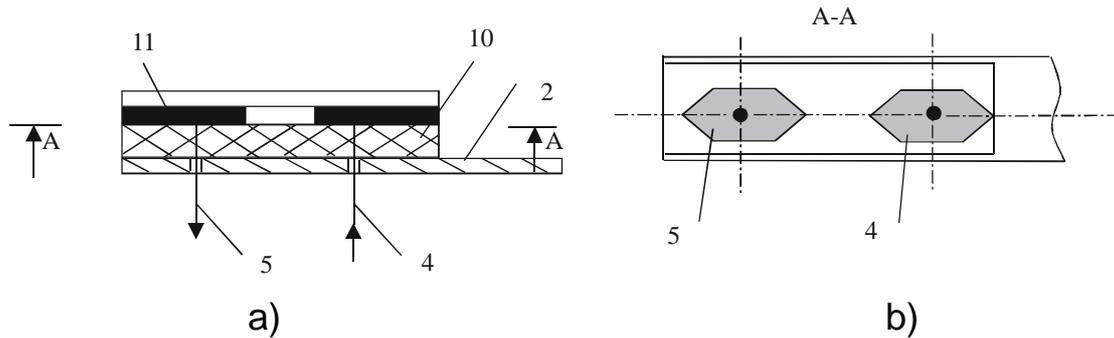


Figure 4. Coupling elements

Construction of coupling elements is shown in Fig. 4 (*a* – side view, *b* – top view). At an edge of the screen 2 is installed dielectric plate 10 made from teflon, in particular. On its surface thin metal strip 11 is fixed where coupling elements 4 and 5 are made by the method of electrochemical etching. Connections with these elements are provided through orifices in the grounded screen 2.

3 CONCLUSION

Suggested methods give ability to measure length of thin elongated articles with high accuracy and speed of operation. It is especially important under technological monitoring and final check of metal articles at acting installations for the production of tubes, rolled metal and other articles. In particular efficiency of these methods and devices based on them is successfully confirmed under their application at tube production plants for on-line length measurements of thin metal tubes.

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