

Force and Mass Measurement in Extended Measuring Range

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Abstract: This study deals with the problem of force and mass measurement in extended measuring range. Described solutions of electrodynamicometer with multi range measuring and universal letter-batch mail scale are both concretely used in practice. The solution applied to universal mail scale is the original solution developed by Electrical Engineering Institute “Nikola Tesla”.

Keywords: Mass measurement, electrodynamicometer, force transducer, multirange measuring, microcontroler.

1 Introduction

Basically, measuring a physical value in extended measuring range is a complex metrological task, especially to provide approximately identical accuracy in the entire range measuring. The width of the measuring range is directly linked to the width of measuring scale of an analogue instrument, resolution and accuracy of the measurement, as well as with the error variation that may appear due to parasitic influences. This problem can be solved not only by changing the measuring range and scale on the measuring instrument, but it is also often required to change the measuring instrument and even the method of measuring.

When measuring electrical values such as current and voltage, this problem is relatively easy to solve by changing the measuring range, i.e., changing the precision resistor. When measuring non-electrical values by electrical means the problem is even more complex, and the difficulty of the problem solution varies from value to value, and from one case to another. The most common solution is increasing the number of measuring transducers of one physical value into an electrical

Manuscript received October 10, 2006.

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signal of different nominal range that should change during the measuring process. However, this is hardly executable in most cases.

Speaking of measuring mass and force by electrical means, in the structure of measuring devices a receiver of mechanical force, i.e. mass load, must be used, which additionally complicates problem solution of force and mass measuring in extended range measuring.

Force of electrodynamicometers, force-generating machines and presses also have to be measured in extended measuring range. Thus, these devices usually have more measuring ranges with nominal values that are often in proportion 1 : 2 : 5 : 10. If a realization of such device for force measuring consists of a single measuring force transducer (MFT), then it is hardly possible to provide the same accuracy for all the range measuring, considering the fact, that the metrological characteristics of MFT are defined on measuring range. It is similar with scales that measure mass by measuring force, i.e. by applying MFT with strain gauge [1]. In the case of universal mail window with limited space and working area, there is not enough space for two scales, so using more electronic scales is often impracticable.

2 Electronic Dynamometer with Multi Range Measuring

There are a few aspects of solving a metrological task of measuring device or instrument. In the foreground of metrological aspect, there are range, accuracy and efficiency of measure. Operational aspect is directed to usability, reliability and successfulness of the solution, as well as simple handling and maintenance of the device or instrument. The solution can also be observed from the physical and economical point of view, which also affects the quality and successfulness of the given solution [2].

There are a few ways to solve the problem of force measuring in extended measuring range. One way is to apply one MFT with such accuracy class that even the lowest range measuring satisfies the demanded accuracy. Second way is one MFT with reduced measured force by lever system. Third way is using more MFT that leads the measured force to MFT of proper range measuring.

This study describes solving the electrodynamicometer with two MFT. The solution is applied to the force-generating machine. Accuracy class of these devices is 1 and 2, and it is defined by relative abundance free error through entire range measuring. The proportion of maximum and minimum force defines the measuring range width of the devices and it amounts 1:100, so it is fairly impossible to perform it with a single MFT [3].

2.1 Electronic dynamometer with two MFT

Two MFT of 10 kN and 100 kN nominal values are applied on force generating machine class 1 for force measuring range from 1 kN to 100 kN. Standard solution of elastic force measuring with two MFT is actually measuring with a single suitable MFT that, depending on the expected measured force, is attached to the measuring circuit. This kind of solution can provide the demanded measuring accuracy. Operationally, it is problematical because MFT has to be physically changed, which decreases measuring efficiency and reliability. Each time MFT is attached to electronic circuit of a measuring device, there has to be a certain period of stabilization, null adjustment and device calibration.

The solution applied to force generating machine solves these problems. Figure 1 shows a diagram of a device for extended force measuring with two MFT.

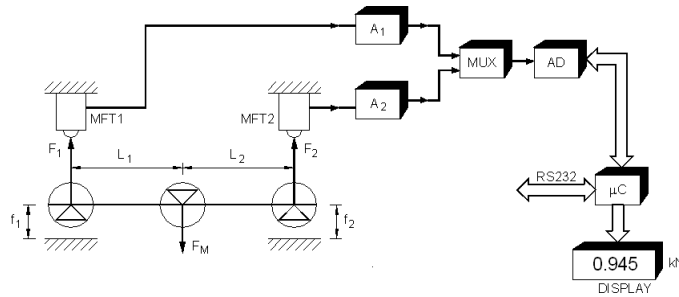


Fig. 1. Electronic dynamometer chart with two MFT.

In the Figure 1, measured (extended) force F_m affects simultaneously both MFT, thus generating reacting forces F_1 and F_2 in both of them. These forces values are determined by L_1 and L_2 pole proportion. When $L_1 = L_2$ these forces will also be equal i.e. $F_1 = F_2 = F_m/2$. Since MFT have different nominal forces of 1:10 proportion, deflections f_1 and f_2 will have the same proportion. It is constructively adjusted in such a way that more than 10 % of MFT overload of less nominal force is leaned on the stand (S) and thus it is precluded from further overload. Statistically, beam system with two bolsters becomes the lever with L_1 and $(L_1 + L_2)$ poles. The force of the bigger transformer F_2 corresponds with measured force F_m in the same way as in the previous case. This is shown in the equation:

$$F_2 = \frac{L_1}{L_1 + L_2} F_m = \frac{1}{2} F_m \quad (1)$$

The discussed case is not entirely a statistical system, but MFT have a certain flexible distortion, which results in deflections f_1 and f_2 , so due to different deflections there will be certain beveling of bracing forces. Since these deflections are

0.5 mm for nominal forces, and the poles L_1 and L_2 are 100 mm, calculation shows that beveling angle is $\cos \alpha = 0.99987$. This value of beveling angle affects the measuring error that is, according to this calculation, less than 0.013 % and can be ignored concerning declared 1 % relative measuring error. This analysis confirms this accuracy concept of using two MFT. What is achieved with such concept?

Solution of electrodynamicometer for (stretched) force measuring enables greater measuring efficacy, better operativeness through simple and more comfortable work with force generating machine. Thanks to modern microcomputer and microelectronic technology, it is possible to improve accuracy and reliability of force measuring.

It was mentioned that both of the MFT are constantly present in the measuring circuit of the electronic electrodynamicometer. Microcontroller continuously monitors the performance of both measuring channels. During the measuring preparation stage, microcontroller performs null adjustment and calibration in accordance with the set program. During the measuring process, it performs measuring signals processing such as automatic amplification, filtration and averaging. According to processed measuring results, microcontroller performs selection of the actual MFT and measuring resolution. It means that demanded measuring accuracy in the sole measuring range of 1kN to 100 kN could be accomplished by measuring resolution automatically during the measuring process. Figure 2 shows measuring resolution change depending on the measured force.

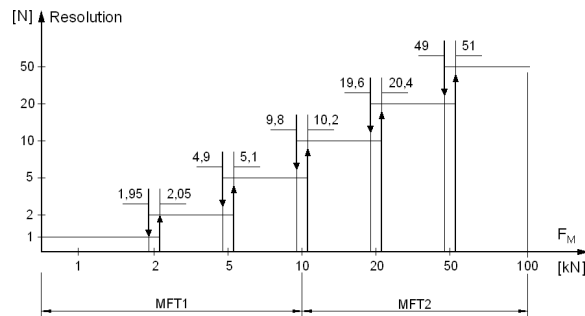


Fig. 2. Measuring resolution change depending on the measured force.

The resolution chart slightly differentiates in rise, i.e. in reduction of measured force. In order to have a correct automatic change of resolution measuring and actual MFT, it is necessary to have certain hysteresis in the decision chart with the width bigger than possible measuring errors in that part of measuring range.

Microcontroller also provides functional connection of electronic dynamometer elements: keyboard, display, amplifier, A/D converter, as well as connection with control system of force generating machine. If the device is mechanically

stopped or if there is any violation of measuring range, the performance of force generating machine is aborted. Microcontroller also provides serial communication of electronic dynamometer and PC, which makes the solution high-graded.

3 Electronic Scale with Multi Range Measuring

Characteristics of modern mass metrology are electronic scales with MFT. These scales are widely used, especially in trade (accuracy class III). In trade, they have almost completely displaced mechanical scales. Electronic scales breakthrough is not easy because of the fact that mechanical scales are very accurate and reliable measures. Allowed relative error of 3rd class scales ranges from 0.1 % to 0.01 %. There are not many types of MFT that can satisfy these accuracy demands, so MFT based on strain gauges is widely used. Dynamometers have load-receivers that define the type of load, i.e. measured force. Scales are different and their whole measuring platform is actually a load-receiver.

Until the first platform type MFT appeared, it was thought that electronic scale had to have at least three MFT. Developing platform type MFT, based on strain gauges, made electronic scales more popular. With development of electronic scales for letters 'Tensopost', Electrical Engineering Institute 'Nikola Tesla' has also developed the original construction of platform type MFT, which completely satisfied metrological demands [4]. However, it has been clear since the very beginning, that for the universal mail scale of 2 kg and 20 kg measuring range, this demand cannot be satisfied with a single MFT.

3.1 Electronic scale with two MFT

At first, universal mail, scale with two measuring transducers had two independent measuring platforms with joint electronic circuits that handle two independent measuring signals. Virtually, it was an electronic scale with two measuring channels, i.e. two measuring ranges. From metrological, operational and economic aspects, such solution was acceptable, but from physical aspect, there was simply no space for two independent measuring platforms at the post office windows.

The solution was found in the mechanical coupling of two MFT. The problem of force measuring in force generating machine had to be solved by a parallel mechanical link of MFT. That was executable by defined vector measured by force, i.e. direction and point of application. This could not be applied on scales with load inside the platform and tight MFT link with the platform. However, in contrast to parallel link, MFT series link is statically correct. What is the MFT series link?

Analogically to current circuit, the same force reaches both MFT. Since these MFT are of different nominal load value (1:10 proportion), loading such MFT com-

position would become a problem, because in the selection of nominal transducers values, the converter of smaller measuring range would be overloaded. The problem was solved by protecting the MFT from overloading as it was done with force generating machine. Figure 3 shows mechanical frame of mail scale measuring platform.

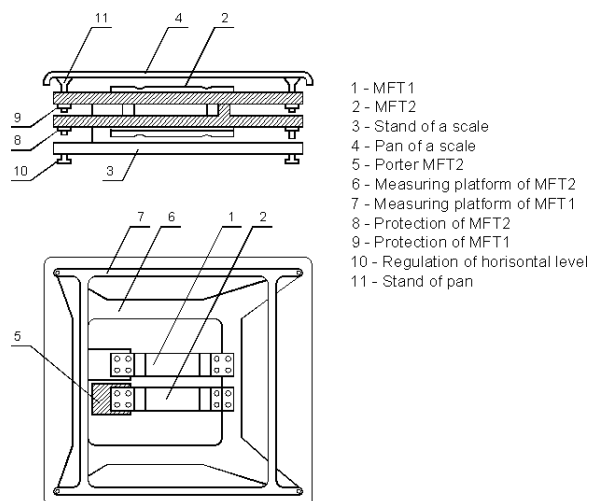


Fig. 3. Mechanical frame of measuring platform with two measuring converters.

In the Figure 3 is shown that MFT 3 of bigger measuring range (20 kg) is mechanically linked to the scale stand in one end; and on the other end it is linked with MFT 1, which is of smaller measuring range (2 kg). The other MFT 1 end is in tight mechanical link with the scale-measuring platform. By putting a letter or a batch on the measuring platform, both MFT are loaded with the same force. Which of the MFT is relevant for the given measured mass is set by processing electronic signals. If the measured mass exceeds MFT measuring range, electronics will take MFT 2 as a valid measuring signal, because MFT 1 will become mechanically protected from overload and its measuring signal will not be valid. This short description of universal scale performance shows that this kind of solution of measuring platform requires 'intelligent electronics' [5]. Figure 4 shows chart of applied electronics on the universal mail scale

Universal mail scale structure is divided into two parts: sensor part (SP) and electronic part (EP). Sensor part consists of measuring platform with two MFT. The electronic part includes a few electronic modules: supply module (SM), two differential amplifiers (DP), multiplexer (MUX), A/D converter and microcontroller. The scale's key element is the microcontroller (μC) which operates and controls per-

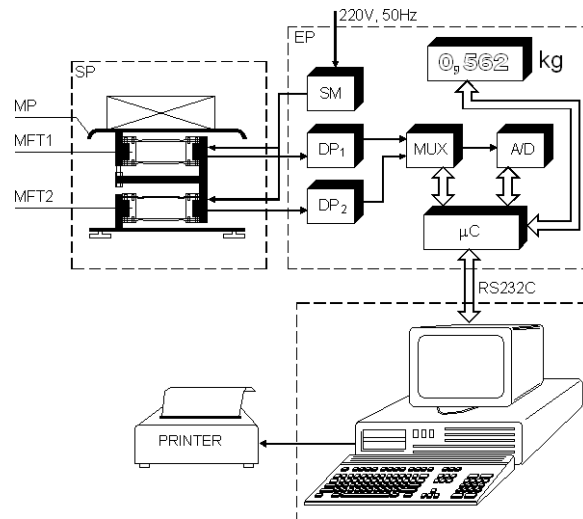


Fig. 4. Universal mail scale chart.

formance of all other scales elements according to its developed software. Modern electronic applied components have a high integration degree; therefore, a single chip is integrated with almost all electronic circuits (DP, MUX, ADC, μC) that are necessary for operation of this kind of scale. The solution of electronic part of the scale has its practical aspects, such as:

- metrological characteristics improvement,
- operational characteristics improvement,
- physical characteristics improvement, reduction of electromagnetic disturbances,
- scale s price reduction.

With this kind of electronic force measuring, applied software is just as important as built-in hardware. In the case of universal mail scale, software is very important element because it provides:

- automatic selection of measuring range and change of measuring resolution,
- automatic scale calibration in case of unloaded measuring platform,
- automatic control of mechanical scale conciliation,
- measuring results on scale s display,
- measuring results transfer to PC.

Research conducted by Electrical Engineering Institute Nikola Tesla shows that the software solutions appliance is equally successful in solving problem of creeping MFT [6], and/or the problem of applying a multifunctional scale [7]. Universal mail scale is connected to PC through serial interface RS 232C. PC can be used in all operations at a universal post-office window as well as in the reception and sending of mail packages (letters and packages).

This kind of universal mail scale solution solves the problem of mail packages mass measuring in wide measuring range with equable relative measuring error. Figure 5 shows universal scale limits of allowed absolute error and two individual scales (letter and batch) in the function of measured mass.

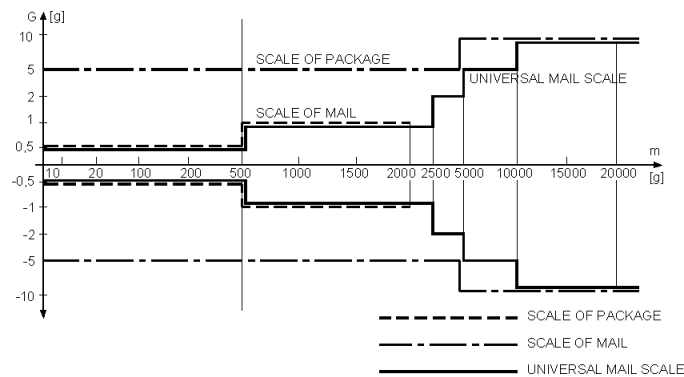


Fig. 5. Limits of allowed absolute error within the measuring range.

Universal mail scale is obviously in advantage over two standard individual scales with 2 and 20 kg measuring range. It is because universal mail scale has narrower limits of allowed absolute measuring error. Universal scale appliance is more favorable not only from metrological aspect, but from other aspects, too, such as operational, physical and economical aspect. The scale in has successfully been used at Serbian post-office windows for years.



Fig. 6. Universal mail scale "Tensolux".

4 Conclusion

The described original solutions of force and mass measuring in extended range measuring are metrologically and technically correct solutions that are confirmed in practice. Microcomputer appliance to electrodynamicometers and electronic scales certainly contribute to higher level of measuring accuracy, reliability and efficacy. The described solutions of force and mass measuring may be applied to solving similar metrological problems with different types of scales such as: counting scale, pressure and torque measuring scale in extended range measuring.

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