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COMPARISON OF DIFFERENT LOAD CHANGERS FOR EMFC-BALANCES

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Abstract – In order to further improve the metrological properties of weighing systems based on the principle of electromagnetic force compensation (EMFC) as well as quality assurance, it is necessary to determine the parameters relevant for the dynamic operation, such as measurement time and controller behavior. This determination is carried out by loading the balance system and observing the indication. Typically this is done by a load changer using different metrological weights. This method is inevitable if metrological traceability is required. However, the conventional procedure of load changing also entails several disadvantages. The number of possible load changes per unit time is limited and the force characteristic during loading is usually unknown and relatively difficult to reproduce or manipulate. Furthermore the fast and sudden exchange of the weights causes mechanical vibrations and a movement of the surrounding air, both of which act as additional disturbances.

In this paper we propose an alternative loading method, with which these shortcomings can be improved and compare it to a conventional system. This method is based on loading the weighing system in a defined manner using a Lorentz-force, allowing the tester to generate a known, virtually arbitrary force characteristic during loading.

It is shown that the Lorentz-force generated load represents a practical alternative to classical weights, offering advantages in reproducibility, dynamics and ability to be automated. Since the proposed method applies a known Lorentz-force to the weighing system it becomes possible to exactly determine the relationship between the force acting on the weighing pan and the resulting behavior of the weighing system.

Keywords check weigher, measurement time, load changer

1. WEIGHING SYSTEM

For the presented investigation a dynamic OEM load cell of the type WZA224, manufactured by the company Satorius (see figure 2) was used.

This load cell has a weighing range of 220 g at a resolution of 0.1 mg. The specified measuring time is 0.6 s [2]. The load cell WZA224 is based on the principle of electromagnetic force compensation. Today, this principle of force measurement represents the state of the art with respect to precision in mass metrology. Balances of this type can also find use in dynamic measurements. Figure 1 shows a schematic design of the balance presented here.

In this EMFC load cell a so called double-sided controller is employed. That means that the lever system of the balance is in mechanical equilibrium at half of the maximum load. Deviations from this load case are countervailed by positive and negative currents through the internal compensation coil.

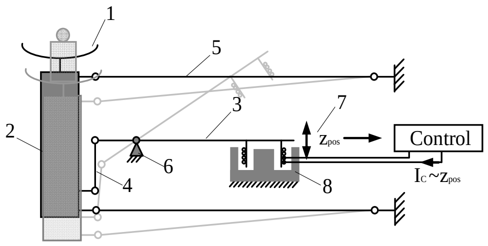


Fig. 1: Schematic design of an EMF balance

1 – Weighing pan
2 – Coupling element
3 – Lever
4 – Coupling band with flexure hinges
5 – Parallel guide with flexure hinges
6 – Lever bearing
7 – Position sensor
8 – Coil and permanent magnet

2. MECHANICAL LOAD CHANGER

For conventionally loading the balance with weights a PC-controlled pneumatic load changer was developed (see figure 2). As actuator a pneumatic cylinder of the company Festo in combination with an electromagnetic valve and a mechanical damper is used

The current configuration of the setup allows load changes using specially designed weights with masses between 1 g and 200 g at frequencies of up to 10 Hz. The carrier for the weights is shaped as a self centering closed taper seat (see figure 3).

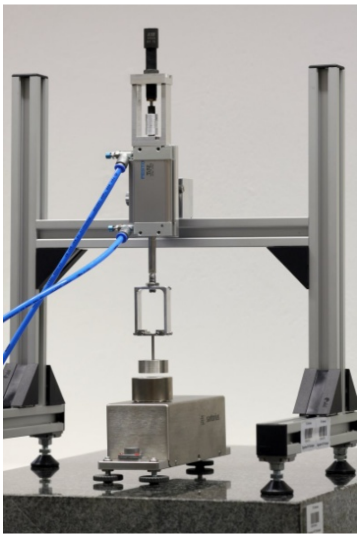


Fig. 2: Pneumatically driven load changer and dynamic EMFC load cell

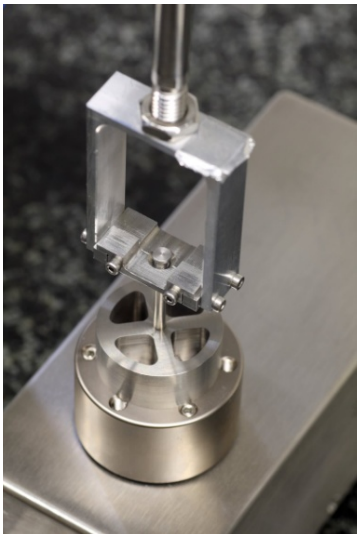
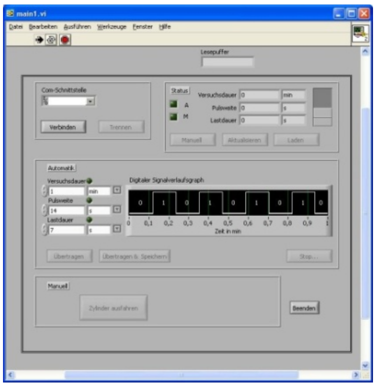


Fig. 3: Specially designed mass piece in carrier

For the control of the load changer a circuit based on a microcontroller was developed. The corresponding software allows a comfortable configuration of the temporal sequence of the load changes (see figure 4).



Status
Versuchsdauer 0 min
Pulsweite 0 s
Lastdauer 0 s

Automatik
Versuchsdauer 1 min
Pulsweite 14 s
Lastdauer 7 s

Fig. 4: Screenshot of the operator panel for controlling the load changer

Different ways of determining the time-force relationship during load changing were tested. Since the loading happens very quickly, the force characteristic cannot be detected sufficiently fast by the EFMC balance. A far higher cut-off frequency can be achieved by piezoelectric load cells. The normalized loading curves for various weights, measured with a piezoelectric load cell are depicted in figure 5. It is evident that the curves exhibit differences attributed to the placement behavior of the different mass pieces. However, a typical loading curve does exist, which results from overlaying a loading impulse onto a static load value. The loading impulse depends on the placement speed and the elastic properties of the weighing system as well as of the support. The EMFC load cell will show a slightly different loading characteristic as its stiffness is different from that of the piezoelectric load cell.

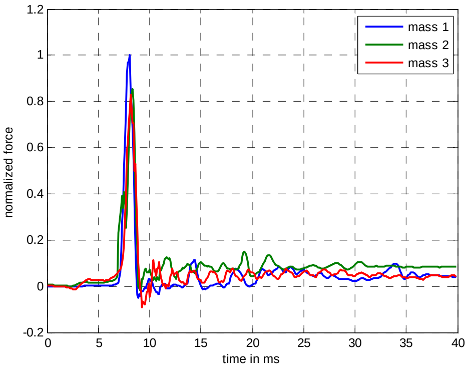


Fig. 5: Normalized loading curves during mechanical load changes on a piezoelectric load cell

To estimate these effects of stiffness of system and support load curves for an EFMC load cell as well as different supports were measured using an acceleration sensor. The acceleration sensor was mounted directly to the mass piece to be loaded. In figure 6 the normalized accelerations during the placement of a mass piece on a controlled EFMC load cell respectively a very stiff support are shown. The maximum acceleration (and thus the maximum loading force) for the EFMC load cell is only half as high as for the stiff support.

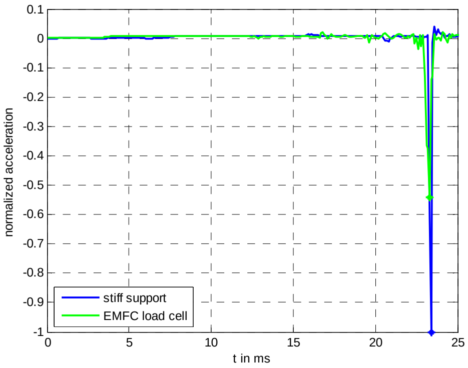


Fig. 6: Normalized Accelerations during placement onto supports of different stiffness

3. LOAD CHANGING BY USING LORENTZ-FORCES

The basic principle of this method of load changing is quite simple. The load is represented by a Lorentz-force which is generated using an electrodynamic linear drive consisting of a coil and a permanent magnet.

In order to avoid magnetic hysteresis and remanence effects influencing the drive, the coil has to be made from materials that are as magnetically neutral as possible. Here a commercial drive of type LA13-12-000A by BEI Kimco Magnetics Division is used. The coil unit of this drive consists of an aluminum carrier (μr=1+2,2 10-5) and a copper coil (μr=1-6,4 10-6). This drive has a force sensitivity of 9,79 N/A and reaches a short-term peak force of 15,6 N [3].

To ensure a frictionless coupling of coil and magnet pot there is no guidance mechanically restricting the movement. Thus an external positioning system is needed to adjust and fix the relative position of coil and permanent magnet. Figure 7 shows pictures of the experimental setup. The magnet is placed on the weighing pan of the balance to be loaded and the coil is mounted to the positioning system which is fixed at the base frame. This setup guarantees that there is no mechanical feedback caused by the lead wire to the coil. The initial load of the balance is now equal to the mass of the permanent magnet. However this preload does not influence the possibility of applying additional Lorentz-forces. Since it matches half the maximum load the balance is at mechanical equilibrium, allowing coverage of the entire load range by driving positive respectively negative currents through the coil.

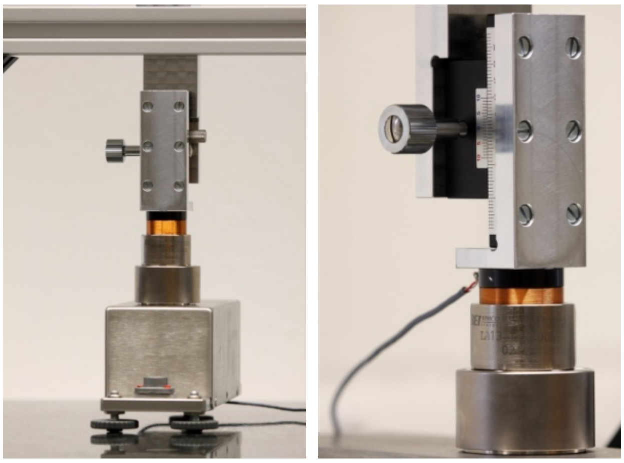


Fig. 7: Setup for load changing by Lorentz-force

With this setup virtually any user-defined load curves can be generated. The current source for driving the coil in the experimental setup was Universal Source 3245 A by Hewlett Packard. This device can generate arbitrary signals at a resolution of 1 million steps. The maximum range in DC-current mode is +/- 100 mA at a voltage limit of +/-8 V [4]. The calculated time constant of the current response to a voltage step is 0.165 ms for the electromagnetic drive.

Hence a calculated value of 100 mA/0.02 ms for the current change rate can be reached if the full voltage span is used. This is equivalent to a force change rate of 50 N/ms. With these theoretical parameters the setup is well suited for dynamic applications. By an integrated GPIB-Interface the device can easily be integrated in a PC based control and data acquisition.

Due to the excellent metrological properties of the applied current source the setup can also be used for the automated testing of the static characteristic (e.g. linearity and hysteresis) of high precision weighing systems. With conventional load changers such investigations are very time consuming.

However, depending on the required measurement uncertainty an exact positioning of the coil inside the permanent magnet has to be ensured. The force-position dependence has a parabolic characteristic. The sensitivity of the force to position changes reaches a minimum at the center position [3].

In contrast to loading using weights, the actual mass dependence of the dynamic behavior of the EMFC balance is not taken into account when loading with Lorentz-forces.

However, this dependence is very small for EMFC balances with a high lever transmission and an adequate pre-loading.

Figure 8 shows the transfer function between the current of the internal coil of the balance and the lever deflection for the EMFC load cell used in the experiments for various masses on the weighing pan. Apparently, the cut-off frequency of the system is almost fully independent of the load. This fact further increases the practical applicability of loading “without weights” using Lorentz-forces.

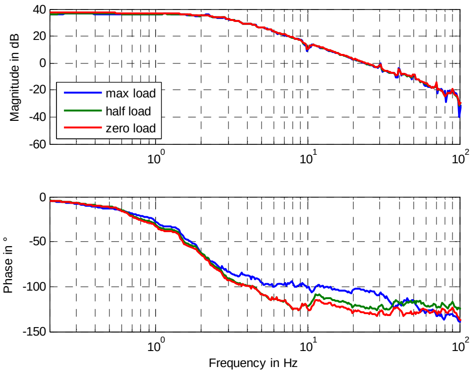


Fig. 8: Mass dependence of the transfer function between coil current and arm deflection

The reason for such behavior is the mechanical configuration of the weighing system (see figure 9).

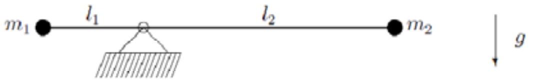
The resonance frequency of an undamped torsional oscillator is:

$$w = \sqrt{\frac{J}{c}}\text{, with } J = J_1 + J_2 \text{ and } J_1 = m_1 l_1^2\text{, } J_2 = m_2 l_2^2$$

If the lever system is at static equilibrium the ratio of the two moments of inertia is:

$$\frac{J_1}{J_2} = \frac{l_1}{l_2} = \frac{m_2}{m_1}$$

It becomes obvious that at high lever transmission the longer side of the lever (l_2) crucially contributes to the moment of inertia of the entire system. Hence in this case mainly the length of the long side of the lever determines the resonance frequency of the balance.



m_1, m_2	mass on the left / right side of the lever
l_1, l_2	length of the left / right side of the lever
g	gravity

Fig. 9: Simplified model of the lever system of an EFMC-balance at equilibrium

Among several possible signals of testing the balance a step shaped Lorentz-force was chosen for loading. This kind of signal is hardly realizable by loading weights. The normalized reaction of the balance to a quasi-step-shaped change in the current through the external coil is shown in figure 10. Knowledge of this transfer behavior can be used to optimize both the mechanics of the balance and the weighing controller.

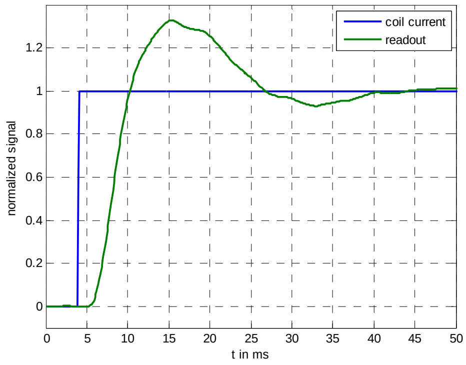


Fig. 10: Response of the balance to a load step induced by a Lorentz-force

4. CONCLUSIONS

In this paper a pneumatically driven load changer with good dynamic properties was presented. During the placement of the weights on the weighing pan the loading curves show a typical characteristic resulting from the superposition of a dynamic loading force and a static load.

The method of loading “without weights” by using the Lorentz-force was proposed as an alternative. Results show that electrodynamic load changer is a useful supplemental method for determining the parameters relevant for the dynamic operation of EFMC-balances.

In contrast to conventional load changers based on metrological weights the Lorentz-force load changer is also applicable for the investigation and calibration of force measurements not in the direction of gravity.

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