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Cutting force measurement of electrical jigsaw by strain gauges

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Abstract. This paper describes a measuring method based on strain gauges for accurate specification of electric jigsaw's cutting force. The goal of the measurement is to provide an overall perspective about generated forces in a jigsaw's gearbox during a cutting period. The lifetime of the tool is affected by these forces primarily. This analysis is part of the research and development project aiming to develop a special linear magnetic brake for realizing automatic lifetime tests of electric jigsaws or similar handheld tools. The accurate specification of cutting force facilitates to define realistic test cycles during the automatic lifetime test. The accuracy and precision resulted by the well described cutting force characteristic and the possibility of automation provide new dimension for lifetime testing of the handheld tools with alternating movement.

1. Introduction

Thanks to the rapid progression of technology more and more new automatic test methods and devices appear in both electrical and machinery fields of industry nowadays. Due to development of modern materials and the advanced and efficient power electronic technologies the most of handheld power tools, garden tools, electric white goods of households and automotive parts can be tested by automated lifetime test methods. However, there are no fully developed test methods and constructions for testing of power tools producing fast-changing alternating movements. The major goal of our research is to develop a contactless braking method based on electromagnetics which allows automated and well reproducible lifetime-testing of these equipment. The problem is fairly difficult due to the relative high frequency of alternating movement and the complex characteristics of cutting force related to one moving period. Furthermore duration of one test cycle may be even a week. These facts require high reliability and robust structure.

The main direction of our research is the analysis of different linear brake constructions (excited by permanent magnets or electromagnets) which are capable to realize the previously mentioned test methods. The building and testing of the first prototype (including excitation coil) has been ended, the applicability of permanent magnets is in the centre of our actual research activities. Besides of the above described topic, analysis of different operational parameters related to the UUT (unit-under-test) is also an important issue. This paper presents a method for the cutting force measurement, which should result an accurate value of the most important operational parameter.

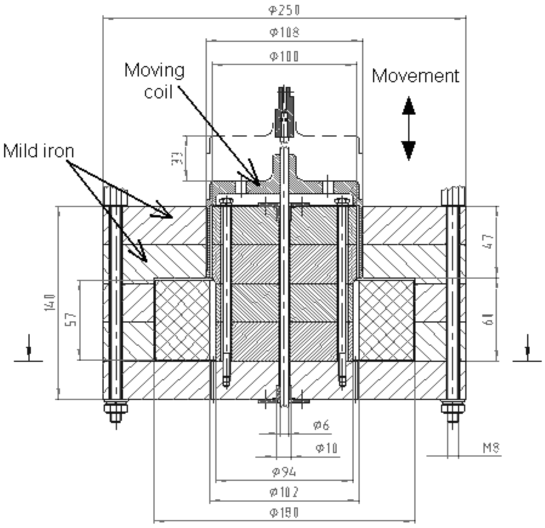

Figure 1. Prototype of dynamic linear brake for handheld tool’s lifetime testing (excited soft iron stator)

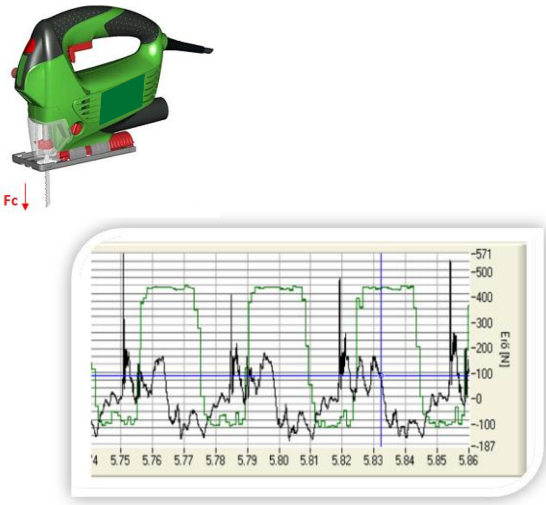

Figure 2. Estimated cutting force - Formed force between the workpiece and the footplate (measured by piezoelectric load cells)

2. Cutting force measurement with strain gauges

There are several possible measuring methods exist for determination of the cutting force of an electrical handheld jigsaw. One of the solutions uses piezoelectric load cells fixed between the workpiece and the footplate. However, the elasticity of both the footplate and the workpiece, the mass of the tool and the flexible downforce applied by the user realize a damped, complex vibration system with more degrees of freedom. The resonance frequency of this system can be close to the alternating frequency of the blade, therefore, the force measured by the load cells can be different from the real cutting force. Determination of the accurate parameter using of complex mathematical models and relationships is necessary to solve the problem.

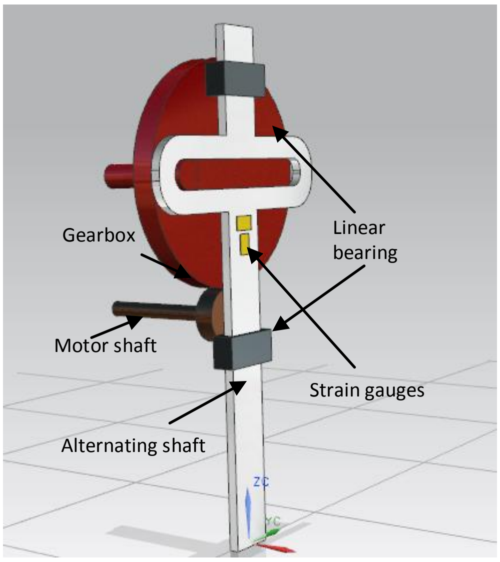

Figure 3. Strain gauges placed on the alternating shaft for measuring the cutting force

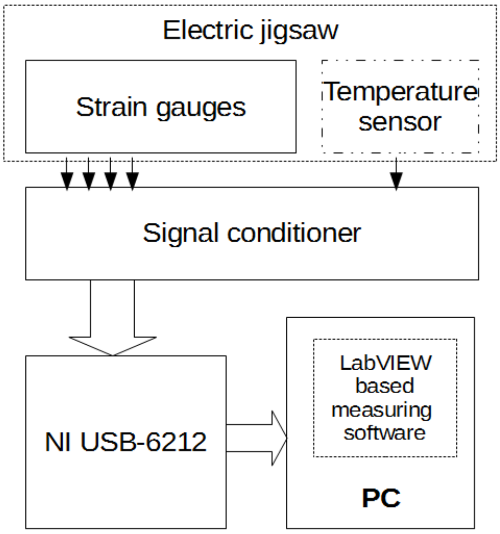

Figure 4. Block diagram of the measurement system including computer-based data acquisition

Figure 2. shows result of the cutting force measurement. Solution described in this paper measures the strain (or compression) of the alternating shaft directly. As the cutting blade is connected to the shaft, deformations measured by strain gauges are proportional to the cutting forces. The layout of the gauges is shown on Figure 3. Mounting place seen on the figure is the only one where the measuring gauges can be mounted due to the position of linear bearing. The gauges placed horizontally are responsible for the temperature compensation of the measuring circuitry and symmetrical placement provides removing of effect of shaft's deflection.

3. Structure of the measuring system

Due to the very small strain of gauges (max. 70με) a signal conditioning circuit provides the appropriate interfacing between the gauges and the computer-based measurement system. This signal conditioner handles the gauges using two Wheatstone-bridge (one for each side) and includes two pieces of AD620 type precision instrumentation amplifier. Both stages are independent from each other and provides 1000 of gain. The power supply includes a simple transformer with $24V_{AC}$ primary voltage to prevent electrical shock during testing. The self-made transformer can provide the corresponding output voltages (±12V, 5V and 24V) via linear voltage regulators to supply all circuit elements. The computer-based measurement system contains a NI USB-6212 type multifunctional data acquisition module. The data acquisition is controlled by a LabVIEW-based measuring software. The zero-adjustment of Wheatstone-bridges is also implemented by the software. The block diagram of the amplifier stage can be seen on Figure 5.

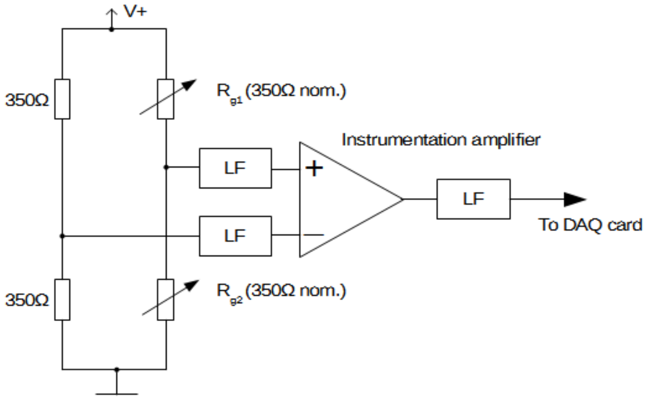

Figure 5. Simplified circuit diagram of one amplifier stage

The strain gauges used in this measurement system are constantan-based KMT-LIAS-06-1.5-350–5E-type thin film gauges. The nominal resistance is 350Ω±0.5%, the gauge factor is 2.05 ±1%. The vertical gauge is responsible for measuring the shaft's vertical strain and the horizontal one compensates the temperature drift. The strain of the shaft (ε) can be calculated by the following equation.

$$\varepsilon = \frac{-4V_r}{GF(1+2V_r)} \quad [4],$$

where V_r is the reference voltage of the bridge and GF is the gauge factor.

The mounting of strain gauges and the assembled measuring circuit are shown on Figure 6.The PCB includes a vibration sensor's driving circuit as well (see below).

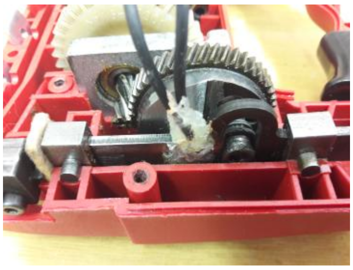

Figure 6.a. Strain gauge mounting

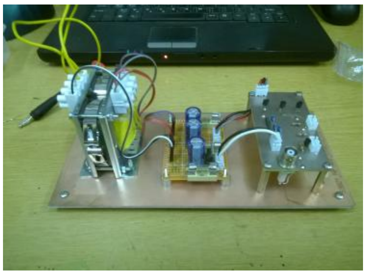

Figure 6.b. Assembled measuring circuit

4. Conclusions of test measurement

The first test results underlined linear relationship between the pulling/compressing force and the output signal in case of small forces. However, when the force is significantly increased, this relationship is becoming nonlinear. In case of large forces the output signal had the same polarity in both pulling and compressing period. To evaluate these results a finite element simulation has been implemented in Comsol Multiphysics 3.5. The applied vertical force was 100N. Simulated horizontal and vertical strain distributions in both "pulling" and "compressing" periods are shown on Figure 7.

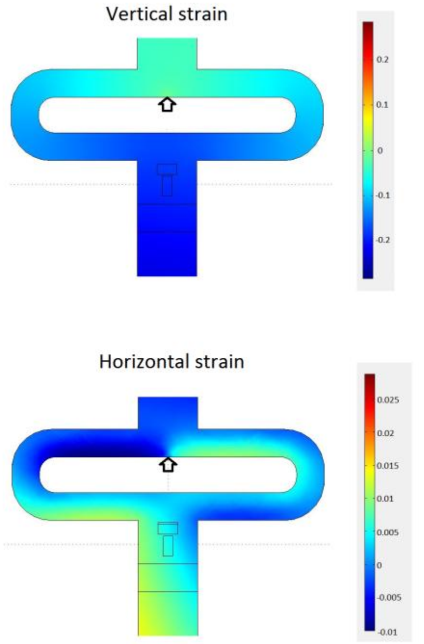

Figure 7.a. Relative **s**train of the alternating shaft during a "pulling" period

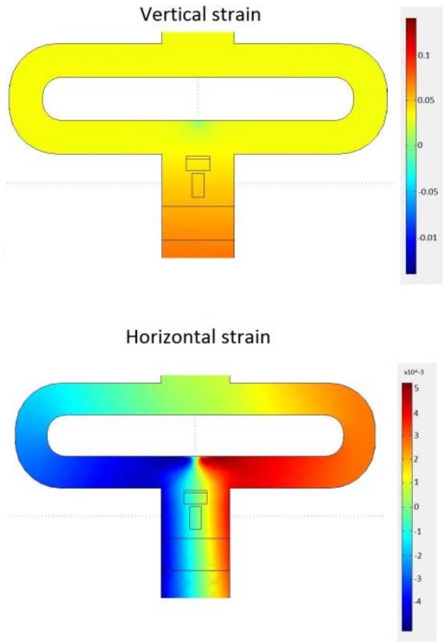

Figure 7.b. Relative strain of the alternating shaft during a "compressing" period

Geometry of the driving unit causes dominant horizontal stretching effect in the shaft during the pulling phase (about 6 times higher than the vertical stretching). In the other, pushing phase of the moving cycle the vertical compression is the dominant effect which is 1.5 times higher than the horizontal stretch). Simulation results also approved these strain/compression ratios. The simulation has also shown that the horizontal compression data carry significant information on the applied force in pulling phase, although, horizontal and vertical strains have opposite directions.

5. Conclusions and further development

Test measurements and results of finite element simulations has shown significant nonlinear relationship between the cutting force and the output voltage of the signal conditioner when using pair of strain gauges in a compensated Wheatstone bridge. This nonlinearity is caused by the arrangement of the gauges, because vertical force causes also significant deformation in the horizontal gauge which is originally used for temperature compensation. Therefore, using of independent for each sensors precise current-source type driving method is necessary, although we should use external temperature compensation and enhanced electrical shielding. Because the geometry of the driving unit is varying point by point using complex mathematical models and relationships are necessary for accurate calculation of the momentary cutting force. For practical realization, an improved signal conditioning unit should be used, and also more accurate finite element simulation models should be built. The simplified block diagram of the signal conditioner mentioned above is shown on Figure 8.

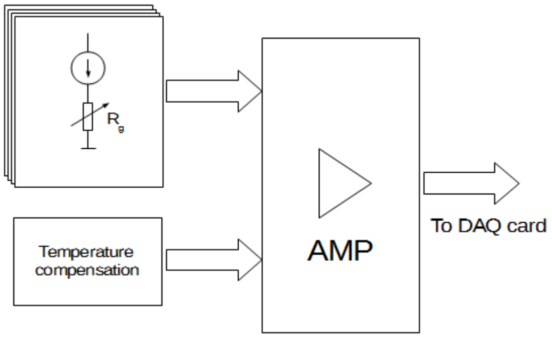

Figure 8. Block diagram of the improved signal conditioning circuit

Since the exact properties of materials applied in the driving unit are unknown, we need to calibrate the complete measuring system including the jigsaw to get the correct relationships between measured parameters and the cutting force. One of the further goals is to extend the measuring system with a piezoelectric accelerometer to measure the vertical vibration. It will help to compare the characterized cutting force and the tool's vertical vibration providing good basics for development of a fairly new method for jigsaws lifetime tests.

Acknowledgments

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