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FACULTY OF COMPUTER SCIENCE AND AUTOMATION

COMPUTER SCIENCE MEETS AUTOMATION

VOLUME II

- **Session 6 - Environmental Systems: Management and Optimisation**
- **Session 7 - New Methods and Technologies for Medicine and Biology**
- **Session 8 - Embedded System Design and Application**
- **Session 9 - Image Processing, Image Analysis and Computer Vision**
- **Session 10 - Mobile Communications**
- **Session 11 - Education in Computer Science and Automation**

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Preface

Dear Participants,

Confronted with the ever-increasing complexity of technical processes and the growing demands on their efficiency, security and flexibility, the scientific world needs to establish new methods of engineering design and new methods of systems operation. The factors likely to affect the design of the smart systems of the future will doubtless include the following:

- As computational costs decrease, it will be possible to apply more complex algorithms, even in real time. These algorithms will take into account system nonlinearities or provide online optimisation of the system's performance.
- New fields of application will be addressed. Interest is now being expressed, beyond that in "classical" technical systems and processes, in environmental systems or medical and bioengineering applications.
- The boundaries between software and hardware design are being eroded. New design methods will include co-design of software and hardware and even of sensor and actuator components.
- Automation will not only replace human operators but will assist, support and supervise humans so that their work is safe and even more effective.
- Networked systems or swarms will be crucial, requiring improvement of the communication within them and study of how their behaviour can be made globally consistent.
- The issues of security and safety, not only during the operation of systems but also in the course of their design, will continue to increase in importance.

The title "Computer Science meets Automation", borne by the 52nd International Scientific Colloquium (IWK) at the Technische Universität Ilmenau, Germany, expresses the desire of scientists and engineers to rise to these challenges, cooperating closely on innovative methods in the two disciplines of computer science and automation.

The IWK has a long tradition going back as far as 1953. In the years before 1989, a major function of the colloquium was to bring together scientists from both sides of the Iron Curtain. Naturally, bonds were also deepened between the countries from the East. Today, the objective of the colloquium is still to bring researchers together. They come from the eastern and western member states of the European Union, and, indeed, from all over the world. All who wish to share their ideas on the points where "Computer Science meets Automation" are addressed by this colloquium at the Technische Universität Ilmenau.

All the University's Faculties have joined forces to ensure that nothing is left out. Control engineering, information science, cybernetics, communication technology and systems engineering – for all of these and their applications (ranging from biological systems to heavy engineering), the issues are being covered.

Together with all the organizers I should like to thank you for your contributions to the conference, ensuring, as they do, a most interesting colloquium programme of an interdisciplinary nature.
I am looking forward to an inspiring colloquium. It promises to be a fine platform for you to present your research, to address new concepts and to meet colleagues in Ilmenau.

Professor Peter Scharff
Rector, TU Ilmenau

Professor Christoph Ament
Head of Organisation

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52^{nd} Internationales Wissenschaftliches Kolloquium
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Maik Rosenberger, Martin J. Schaub, Susanne C. N. Töpfer, Gerhard Linß

Investigation of efficient strain measurements at smallest areas applying the time to digital (TDC) principle

ABSTRACT

Mechanical stresses can significantly exert a large negative influence on stability, accuracy, maximum allowable forces, operational reliability and durability. Such irregular forces occur also at manual electronic internal and external measuring gauges, for example so-called Quicktester. These measuring instruments are used for fast and precise measurements of inside flutes and inside diameters, as well as for thickness measurements. Through different operation positions and irregular loads, applied on the measuring gauge arm by the user, the measuring arm of the instrument is deformed within the µm range. Thus, the precise determination of the deflection is a decisive advantage for minimising measuring deviations.

The paper at hand presents a novel method for strain measurements exemplified at a Quicktester measuring gauge. The method is based on the application of miniature strain gauges and on the signal analysis with the time to digital principle (TDC). Typically the application of miniature strain gauges is characterised by minimal output signals. In addition the cost criterion and the energy efficiency play an important role for mobile measuring instruments. Thus, an application circuit based on new time to digital (TDC) procedures according to the Picostrain method was developed and successfully applied with miniature strain gauges. The paper presents experimental results regarding temperature characteristic, linearity and resolution. Deflections within the µm range could be stably measured.

INTRODUCTION

Each technical system is subjected to most different environmental conditions and loads during its whole life cycle. In most cases these loads cause mechanical stress within the technical system. Mechanical stress has a negative influence on several properties, e.g. mechanical strength, accuracy and maximal achievable life span.

Up to now it was common to investigate mechanical stresses during the development period and to try to eliminate any influence of them on the system. This implies increased safety factors for the mechanics, oversize of components and increased development and manufacturing costs. In order to minimise these disadvantages it is inevitably important to record data about the mechanical stresses during the whole product life cycle [1]. This applies similarly to large machines as well as to small mechanical measuring instruments such as an electromechanical measuring gauge by the company Kröplin for example. Aim is primarily the reduction of measuring uncertainty for these highly precise manual gauges but also efficient material usage, increased quality and product safety. First tests with strain gauges have been performed by A. C. Ruge in 1938. Thereby, the fundamental of this measurement method was the change of the electrical resistance of metals under strain or under compression [2].

The electromechanical, quick measuring gauges possess a fixed and a movable measuring arm. The movable measuring arm is pressed on the measuring object with a defined spring force. The fixed arm is pressed on the measuring object by the operator. The measuring arm is deformed by several µm due to the contact load. Thus, it is necessary to measure the load of the fixed measuring arm during each measurement. Special challenges for the integration of a suitable measuring unit into such an electromechanical, quick measuring gauge are minimum power consumption, for the measuring gauge is battery powered, and minimum installation place for the measuring sensors and its electronic circuitry.

FUNDAMENTALS OF STRAIN MEASUREMENTS

Measurements of mechanical stress using strain gauges are widely deployed in industrial applications. Typical problems, when applying strain gauges, are nonlinear material properties of the adhesives, temperature drift of the strain gauges itself and irregular behaviour of the material exposed to stress. According to Thomson and Wheatstone the basic resistance of a material is:

$$R_0 = \frac{\rho \cdot l}{A_{cross-section}} \qquad (1)$$

where:

ρ - specific resistance

l - conductor length

A - conductor cross-section.

The strain dependent change in resistance R is decisive for measurements with strain gauges, see Eq. 2.

$$R = R_0 \cdot (1 + k \cdot \varepsilon) \qquad (2)$$

where:
R_0 - basic resistance
k - strain sensitivity
ε - change in length (strain).

Aim of the application is the maximisation of the sensitivity of the strain sensitive elements. Thereby R_0 and k are constants. The stress dependent strain ε changes at mechanical loading. As far as constructively possible the strain ε at the measuring area should be maximal. The factor k of metallic strain gauges amounts to 2.05 (constantan). Basically a large factor k is linked to a high sensitivity. However, specifically for semiconductor strain gauges a large factor k also entails an unfavourable temperature characteristic, see [3] page 43. Often deployed measuring analysis methods utilising measuring bridges are detailed in [4].

A new method for the analysis of a strain gauge measuring bridges has been investigated with the help of TDCs, whereby the Picostrain principle was applied. This method was the experimental basis for further investigations. The discharge time of a capacitor is measured with a TDC. The change in discharge time of the capacitor is proportional to the strain [5]. The capacitor is discharged by the resistance of a strain gauge down to an arbitrary switching threshold. The discharge times are compared and the related strains are calculated [6].

PICOSTRAIN TDC TECHNIQUES FOR SMALL STRAIN GAUGES

The experiments and the comparison of different measuring amplifier including an analogue-to-digital converter (ADC) with a measuring amplifier based on the TDC principle have proven, that the ACAM Picostrain system is the best choice. It is an integrated system for the analysis of the strain gauges. It requires no further high-consumption components, such as amplifiers, and is characterised by a low power consumption. A special advantage lies in the fact that no Wheatstone measuring bridge with 4 strain gauges is necessary. Two strain gauges suffice in order to attain maximum accuracy. Tests with four strain gauges did not result in a gain of accuracy. Investigations in suitable miniature strain gauges yielded the strain gauge 1-LY11-3/350 by the company HBM as most suitable [7] (Fig. 1a). This strain gauge has a basic resistance of 350 ohms which is a prerequisite for the application of the TDC principle. Fig. 1b illustrates a mounted strain gauge on a measuring arm with an active measuring area of app. 4.5 mm². Fig. 1c shows the general measuring setup.

Fig. 1: a) Strain gauge 1-LY11-3/350, b) Measuring area of the strain gauge c) Test setup

Aim of the experiments was the determination of the smallest measurable strain signal. Strains caused by a contact pressure of 3N exerted by the operator amount to up to 42 µm/m at one measuring arm. Using the Picostrain amplifier enables measuring frequencies of up to 50 kHz [8]. The measuring software of the company ACAM was utilised for the analysis of the measurements at the PC. For the experiments two strain gauges were mounted on the top and bottom side of different measuring arms. Afterwards defined loads were applied (Fig. 2). The maximum load of the measuring arms equals 3 N. Each larger load is an inappropriate operation of the measuring device.

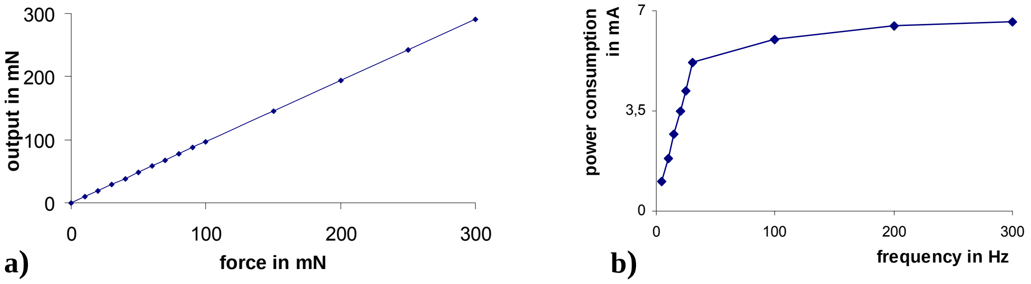

Fig. 2: a) Linearity of the measurement signal b) Power consumption vs. frequency of the TDC circuit

After the experiments investigating the fundamentals the overall system was optimised. The TDC principle offers the opportunity to define most different parameters before starting the measurement. For the integration into a battery powered measuring device an optimal compromise between measuring uncertainty, measuring speed and power consumption had to be identified. A larger measuring frequency is always linked to a larger power consumption (Fig. 2b). A standard delta-sigma-converter which is a special type of an ADC was applied for comparison measurements. In comparison to the TDC method the power consumption of this standard ADC was seven times larger.

Furthermore the TDC principle provides a number of filter functions which had to be adapted for the application at the Quicktester. With the help of test plans an effective resolution of the strain of 15 bits was achieved. Further experiments were focussed on the electrical cable connections between the strain gauges and the TDC Picostrain chip. Thereby screened and firmly fixed coaxial cables turned out to be the best solution.

A stable voltage supply is decisive for enabling the highly precise time measurements with the TDC method. Therefore tests with different voltage supplies like a step-up-controller, a drop-down-controllers and various batteries were performed. The voltage supply based on a drop-down-controller with a battery delivered very good measuring results (Fig. 3a). On contrast the base noise is amplified by factor five when a step-up-controller is utilised (Fig. 3b).

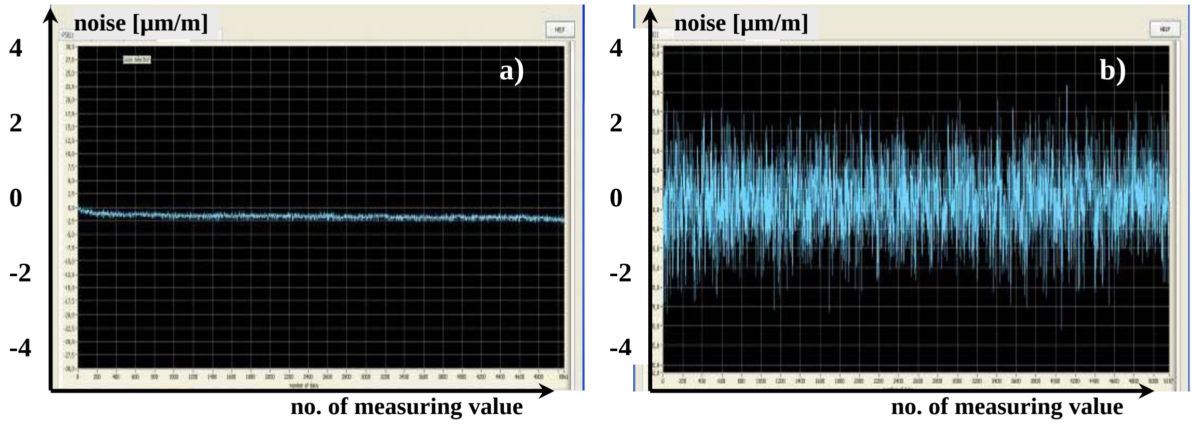

Fig. 3: (a) Base noise of the battery ± 0.07 µm/m b) Base noise with a step-up-controller ± 3.5 µm/m

EXPERIMENTAL RESULTS

For the integration into Quicktesters by Kröplin an extremely low energy strain measuring system has been developed. The optimal position of miniature strain gauges, namely 1-LY11-350 by the company HBM, on the measuring arms were calculated and tested (Fig. 4a). A strain resolution of 0.14 µm/m has been attained with the Picostrain measuring bridge. A minimal power consumption of 5.14 mA at a measuring frequency of 30 Hz poses an ideal compromise between these both parameters. The measuring results prove that the chosen measuring setup is optimal for the integration into Quicktesters. All relevant hard- and software parameters for the integration have been considered. A long battery life span and a high resolution of the measuring arm deformation is enabled.

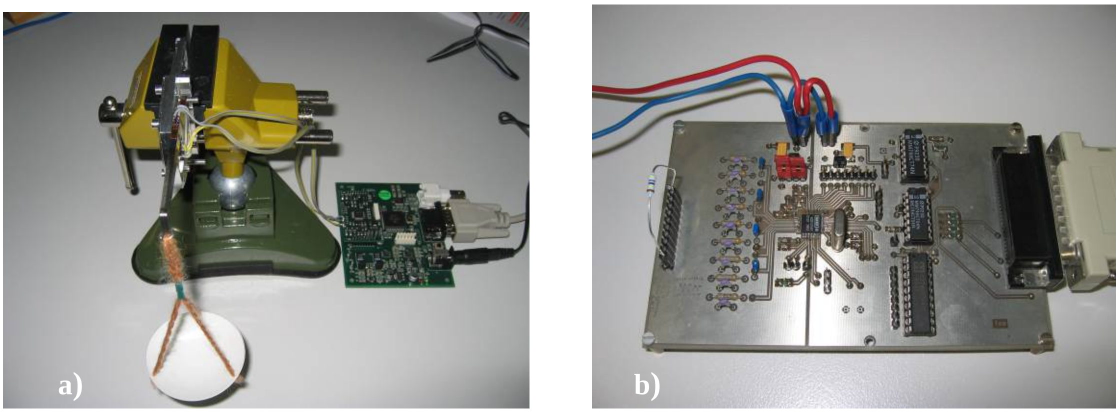

Fig. 4: (a) Test setup for linearity measurements (b) Deployed standard ADC

CONCLUSION

The experiments have proven that the deployment of the TDC principle for strain measurement is ideal for electromechanical measuring gauges such as the Quicktester. This method enables highly precise strain measurements at minimum power consumption. Furthermore the required installation space is minimal and no expensive and high-stable reference voltage supply and no additional measuring amplifiers are required. Comparisons with standard ADC solutions (Fig. 4b) yield the result that these are more cost-intensive and consume more power. When using the TDC principle special care must be put on the cable connection. Finally, the appropriate type of voltage supply (drop-down controller) must be used.

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