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FROM DIGITAL DEVICE UNDER TEST TO DIGITAL CALIBRATION CERTIFICATE. CHALLENGES AND SOLUTIONS FOR THE CALIBRATION OF MEASURING INSTRUMENTS AND SENSORS IN THE DIGITAL FUTURE

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Abstract – The digital transition challenges calibration laboratories on many levels. On the one hand, the test items are changing from analog sensors and measuring instruments to fully digital devices (DUT – devices under test) and, on the other hand, the analog printed calibration certificate is increasingly supplemented by digital data exchange or will be replaced by the DCC in the medium term. The authors have to deal with both challenges as manufacturers of calibration systems and as operators of an accredited calibration laboratory. This paper tries to show why both areas are closely linked and how SPEKTRA deals with it.

Keywords: Digital transducers, calibration data handling, DCC

1. FROM ANALOG TO DIGITAL DUT

As a manufacturer of test systems in sensor production, SPEKTRA was already confronted with the transition from sensors with analog output to sensors with digital output more than 10 years ago. While accurate measurement of the analog sensor signal was the most important aspect of the test systems for analog sensors, the systems for digital sensors had to be able to be adapted very flexibly to various digital hardware interfaces and required a powerful development environment for test software. Analog measurements only played a subordinate role.

In the case of calibration systems for calibration laboratories, which SPEKTRA also manufactures, this transition is not quite as fast and, above all, complete. About nine years ago, we were confronted for the first time with the task of having to calibrate sensors with a digital output. At that time, this concerned sensors with a DTI interface, as used primarily in crash test laboratories in the automotive industry. Since the purely analog CS18 calibration systems at that time were not prepared for digital sensors, a data recorder of the sensor manufacturer had to be integrated as a "hardware interface" and the necessary extension of the software was made controllable via additional menu items, which could not be embedded very elegantly into the concept of the calibration software. The reference sensors in this system continued to be analog sensors and this was retained when SPEKTRA set out to develop a new generation of calibration systems. The new generation calibration systems now combines precise analog measurement channels with a flexibly configurable interface card that was adopted from the production test systems. In addition to the adapted hardware, the software of the new generation of calibration systems has also been completely revised in order to be able to integrate digital and analog DUTs in a similar way and to make operation easier for the operator (see Fig. 1).

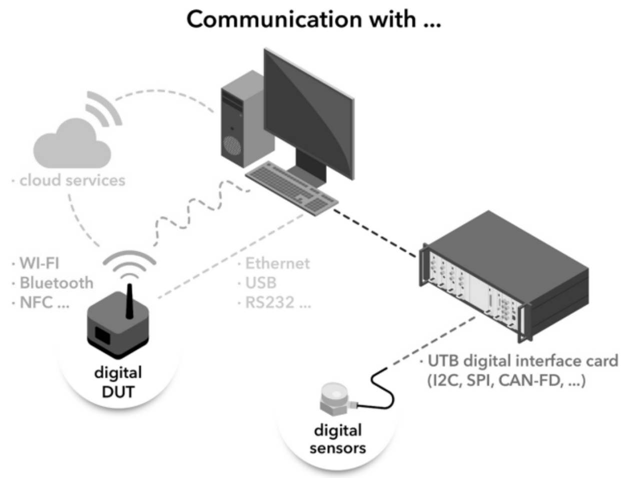

Fig. 1: A new generation of calibration systems must be able to communicate with any kind of digital DUT

1.1. Calibration of digital DUT's - Challenges

As described above, the calibration of digital DUTs requires not only flexible hardware, but above all software that can handle these DUTs. For many DUTs the described interface card is not necessary at all, because they use an interface that is typically also located in a PC. This includes, for example, measuring devices and sensors that are connected via USB or Ethernet interface. The challenge here is not the hardware interface but the architecture of the calibration software, which must be able to communicate with any device. One way to meet this challenge is to establish a programming interface for driver software in the calibration software. Specific drivers can then be programmed for this interface to handle communication with a specific digital DUT. The programming of the drivers themselves can take place, for example, in a modern programming language such as Python. The core of the calibration software would not be touched and the validation of the calibration software could be limited to a validation of the driver software, which e.g.

has to output the same measured value as the display of the measuring device shows it.

As elegant as the approach may seem, however, the challenge is to create a programming interface that can handle different types of data streams. For example, digital sensors can output the measured values as a continuous data stream representing the time signal of the measurand, while measuring devices output a time-averaged measurand, possibly even filtered with a weighting filter. The interface must ensure that the calibration software 'knows' what kind of data stream it is being passed in order to apply the correct calibration procedure, i.e. to process the data from the analog reference sensor channel accordingly and compare it with the data from the DUT. In turn, the programmers of the drivers must ensure that they use the programming interface of the software correctly and, for example, pass the correct context information about the type of data stream. This will typically not be the task of an operator of the calibration system, but will be performed by a supervisor or the manufacturer of the calibration system.

1.2 How to handle the complexity of analog and digital DUTs?

The above shows that the transition from a purely analog calibration system to a system that can calibrate analog and digital DUTs is a major challenge for the hardware and software architecture. But how can the operator of the system deal with the variety of different DUTs, which can also be configured differently? Digital sensors as well as measuring devices often allow to set measuring ranges or filters, for example. How can the operator avoid making mistakes?

This is where the real change that results from the digital transition in the calibration laboratory becomes apparent. The calibration system used must not only be a precise measuring instrument, but must also provide more and more information about the DUTs for the operator and thus help to avoid operating errors. Furthermore, it must be capable to output the calibration data in a human readable format as well as in a machine readable format that can be read e.g. by the DUT itself or by measurement software that uses the calibration results. Data processing and storage becomes a new major task for the software of the calibration system or a software that supports the whole workflow of a calibration laboratory and works closely together with the calibration system.

At SPEKTRA we decided to separate the measurement itself, which is the task of the calibration system software, from the data processing in the laboratory workflow. The calibration software takes care of the signal processing, signal filtering, comparison of measurement data or whatever is necessary for the calibration of a DUT. A separate data management software takes care of the storage of DUT data and of calibration data on a database server and is also capable to output the calibration data in any required output format. A future version of this software will also be able to manage the workload between different calibration stations in a laboratory or to send notifications to the customer about the status of their calibration order. But both, the calibration software as well as the workflow and DUT management software use the same database backend to store their data.

For this purpose, the database must be able to store any types of DUTs with their very different technical characteristics. This concerns properties such as the number of sensor axes or input channels or information on the correct selection of signal conditioners or, in the case of digital DUTs, the correct driver. In addition to these very different technical data, it must be possible to store additional administrative data or documents, with these data having a uniform structure. So how do you store the data for such different devices as a multi-axis sensor or a multi-channel vibration meter, etc. in one database? The solution is to store only a few administrative data for identification of the DUT in the fields of a database table and to store the technical properties as XML data in a special field for this data type. For each class of DUTs, a separate XML schema is defined to describe the properties, and the calibration software must then be able to read the information about the DUT objects stored in the XML data and use it for the calibration process. For example, in the case of digital DUTs, this also includes the information about the driver that must be loaded to calibrate the DUT. Another advantage of this approach is that it allows data from DUTs of varying complexity to be stored. For this purpose, an unlimited number of measurement channels or sensor axes can be added to each DUT, and each of these channels can in turn measure different quantities. Thus, a single-axis accelerometer can be described in the same way as a multi-axis IMU sensor or multi-channel sound level meter. Each channel / axis has its own XML schema to describe its technical properties.

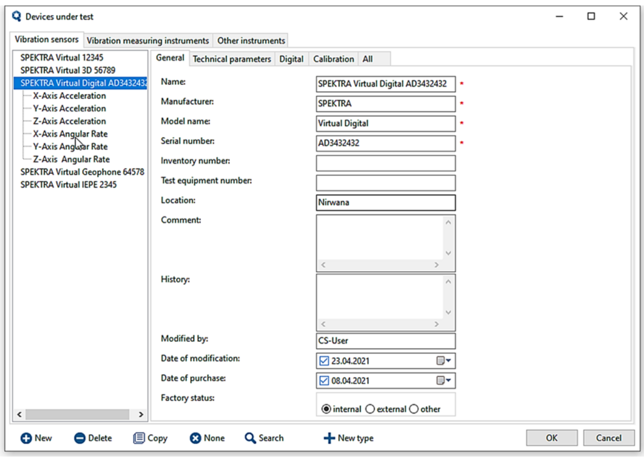

Fig. 2: The DUT database allows to manage an unlimited number of measurement channels / axis for each DUT. Each channel / axis can measure a different measurand.

If the DUT has been correctly created in the database, the operator no longer has to worry about choosing the right driver and possibly setting parameters, but can concentrate entirely on mounting the DUT and the measurement process. Since the software for managing the workflow and the DUTs accesses the same database, the operator's work can be simplified even further and secured against operating errors. For this purpose, the data of a test setup is additionally stored for each DUT, which controls the measurement sequence, e.g. defines the frequency points and amplitudes at which the measurements are to be performed. The operator can now search for the DUT to be calibrated in the test equipment software and give the command to transfer the DUT data together with the test setup to the calibration software and start the measurement.

2. FROM PAPER TO DIGITAL CALIBRATION CERTIFICATES

After a sensor has been calibrated, the calibration data must be saved. Again, the question arises in which format the data should be stored and in which format the data is given to the customer.

XML files have proven to be a very flexible format for saving calibration data. For this purpose, an XML schema was designed which, for reasons of traceability of the measurements, contains not only the measurement data but also detailed data of the measurement system. This includes the characteristics and serial numbers of all components used in the calibration system, details of settings and test setup, information on adapters and measurement cables used, and information on the measurement uncertainty at the individual measurement points. To ensure that the data is tamper-proof, it is additionally secured with a hash value that allows manipulations of the data to be detected.

Since this extensive data collection is not necessary for the user of the calibration data, a calibration certificate is created for him from it. In the past, such a calibration certificate was actually a printed document signed with a pen, which had the disadvantage that the calibration data could not simply be imported into measuring systems for further use, but had to be transcribed. In the meantime, calibration certificates are preferably stored and passed on to the customer in the form of PDF files, but even this format is still a kind of 'printed' document that is only conditionally suitable for data exchange with measuring systems.

As manufacturers of calibration systems, the authors have therefore been confronted for some years now with customer requirements to output the calibration data in certain exchange formats or even to write them directly into the customer's databases. With the upcoming Digital Calibration Certificate (DCC) developed under the leadership of PTB, a standardized XML format will now also be created which, in addition to a regulated part with information on the traceability of the calibration system used, the specification of units, etc., also has an unregulated part in which the calibration data are stored for exchange between devices.

Our new approach is therefore to implement a type of middleware that performs several tasks. On the one hand, it can read calibration data from different sources and convert it into an internal JSON format that can store very different types of calibration data and is also extensible for new DUT classes and their calibration data. On the other hand, the application also works as a viewer that clearly displays the data in tables and graphs. Not only is the measurement data loaded, but also all relevant data about the calibration system and the test specimen. Further functions of the viewer allow e.g. to merge the data from several calibration files, as it is needed e.g. for the calibration of multi-axis sensors or multi-channel signal conditioners. The source data is always protected against manipulation, as it cannot be edited in the application interface, nor can the JSON file be modified unnoticed in an external editor, as it is secured with a hash code.

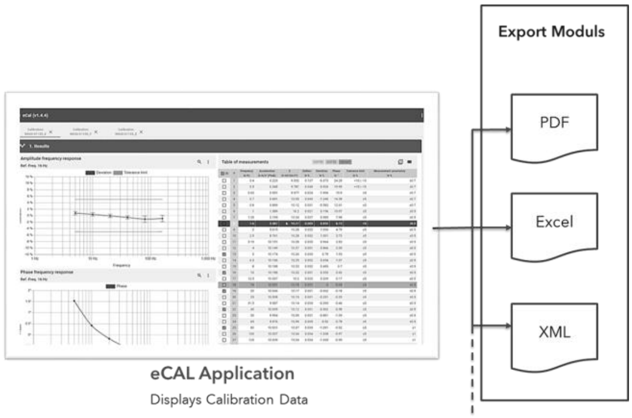

Fig. 3: A new application works as a middleware that allows to display the calibration results and transform it via export modules into several output formats

Furthermore, the application allows the output of the data by means of export modules in any output formats. PDF files for printable calibration certificates can be generated e.g. by means of an integrated report generator, for which templates are created, selected by the operator and filled with the calibration data by mouse click. Alternatively, export modules can be written that convert the JSON data into any other output format. The Python programming language, which already provides libraries for handling JSON and XML data, can be used to write such modules. If there is an XML schema for an XML export format, for example, then this can be easily transformed into a program module that allows the XML nodes to be addressed as properties of an object and to be filled with data. For example, an export module can also be written for the digital calibration certificate DCC or for exchange formats such as EQX/E2X.

This export process is also tamper-proof, since the operator cannot intervene in the data exchange. He can only select prepared templates for PDF files or export modules. Nevertheless, in order to improve the quality control of the calibration process, this application will be expanded in the next expansion step to include a four-eye check of the documents generated and also a function that allows the integration of software for digitally signing the documents. For this purpose, a workflow module is necessary, which presents the created documents together with the original data to one or more supervisors for review and forwards the documents to a digital signature software upon approval. For this purpose, the viewer module must be extended so that it can display the original data and the data of the output document together. For example, it must be possible, to display the embedded human readable document in a DCC side-by-side with the original data.

In a purely digital organized calibration laboratory, however, even more parts of the calibration workflow have to be converted. This includes, for example, the distribution of digital documents after the signing process. Ideally, the documents should be made available to the customer via a secure data cloud. To do this, the documents must be automatically stored on the cloud server in an area that is only accessible to the customer, and the customer must be notified that the documents are available. However, for this part of the workflow to be automated, the documents must contain metadata that allows them to be associated with a customer and an order. This means that other parts of the workflow must be digitized and, for example, data must be exchanged with third-party programs. Customer and order data must be imported from an ERP system, and for the logistical process, the test specimens must be registered when they arrive at the laboratory and assigned to an order. Likewise, at the end of the calibration process, delivery bills as well as invoices have to be written and the DUTs have to be registered for shipment with various parcel services. Here, too, data exchange with an ERP system and the software interfaces of the shipping service providers is necessary.

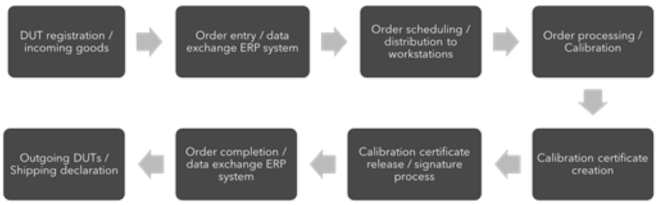

Fig. 4: Workflow in a calibration laboratory that has to be digitized

In the authors' lab, tools that support these workflow steps have been available for several years. However, these tools were created as stand-alone applications and therefore not always easy to use for the personnel involved in the calibration process. Several programs have to be open at the same time and an overview of the entire workflow has not been possible until now. For this reason, the tool described above, which was originally intended only for generating calibration documents, is now being expanded into an application in which all the steps of a calibration workflow in a laboratory are mapped in individual modules. Depending on the workstation, different modules will be offered, which always allow the operator an overview of the tasks to be completed and automate the data exchange between the process steps or modules.

3. CONCLUSIONS

Calibration laboratories are currently challenged to master a changeover process on two digital fronts. On the one hand, the test items are becoming increasingly digital and the proportion of analogue measurement technology that needs to be calibrated will decline in the future. For this purpose, the calibration systems must be prepared in such a way that they can calibrate both analogue and digital DUTs. In this context, the variety of digital interfaces and devices requires an architecture of the calibration system that can handle different digital hardware interfaces as well as flexibly adapt to the communication with these devices. Concepts that allow flexible expandability of the calibration system by means of configurable hardware and modular software drivers are required for this.

On the other hand, however, all process steps of a laboratory workflow must be digitized and flexible tools for a data exchange with the customer of the laboratory must be established. In ideal circumstances the calibration system will be able to exchange calibration data all-automatically with the measurement system that uses the data. The measurement system should be able to verify the calibration data and its traceability in such a case automatically. An internationally standardized digital calibration certificate DCC will be an important first step forward to such a future scenario.

REFERENCES

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