IMEKO 22nd TC3, 12th TC5 and 3rd TC 22 International Conferences
3 to 5 February, 2014, Cape Town, Republic of South Africa

THE ULTRA-PRECISION INSTRUMENT DMP 41 – FIRST EXPERIENCES & APROPRIATE FILTER SETTINGS

A.Schäfer

Hottinger Baldwin Messtechnik GmbH (HBM), Darmstadt, Germany, andre.schaefer@hbm.com

Abstract: Traceability of force / torque laboratories around the world widely relies on the strain gauge principle. In order to reach a high overall accuracy of the measuring chain reference transducers always have to be completed by an ultra-precision instrument for strain gauges. Therefore a very special architecture of A/D conversion & signal processing is used. GUI and interface realization determines the good interconnectivity of the device.

Keywords: Precision instrument, strain gauge, amplifier, high resolution, high stability, filter characteristics

1. INTRODUCTION

Recently HBM introduced its new ultra-precision instrument DMP41 (Figures 1, 2). The outline and the technical data of the instrument have been described in [1].

a)

b)

Figure 1 HBM´s new ultra-precision instrument DMP41
a)"Measuring" mode; b) "Setting" mode

a) b)

Figure 2: Examples for touchscreen display of DMP41
a)"Measuring" mode; b) "Setting" mode

The DMP41 precision amplifier shows its strengths in particular with high-precision comparison measurements of mechanical quantities [3]. It is HBM´s most precise amplifier for strain gauge (SG)-based measurement. The DMP series has been continuously developed by HBM for over 30 years.

The precision amplifier supports simultaneous measurement with multiple channels. The version DMP41-T2 supports two simultaneous channels; the version DMP41-T6 supports six simultaneous channels.

Moreover, DMP41 offers even higher noise immunity than its predecessor DMP40. So the accuracy class 0.0005 is even maintained at electric field strength of 10V/m. Previously under these conditions DMP 40 only allowed accuracy class 0.005.

Its state-of-the-art interfaces allow integration with modern laboratory network environments in many different ways. Metrology institutes can trust that they get maximum precision by using our sophisticated instrument.

The four main principles used to reach the accuracy are the Wheatstone bridge, the six wire circuit and the use of the carrier frequency and the symmetric voltage architecture.

The first principle, the Wheatstone bridge, allows a very sensitive detection of smallest resistive changes of the strain gages inside the force, torque or pressure transducers connected to the device. The primary task of the amplifier is to raise the level of the bridge circuit´s output from the millivolt region to a number of volts, while the amplified signal voltage should be a perfect reproduction of the measured variable [4].

The second principle is the six wire connection comes into play at the time the actual supply voltage deviates from reference supply voltage. In this case the generator, controlled by the comparator, increases its voltage until the sensing leads signal is the same as the from reference supply voltage [5]. So the six wire connection keeps the supply voltage at constant level.

The third principle and maybe this is the most is important one, is the use of the carrier frequency (CF) architecture, showing significant advantages over direct current (DC) architecture in terms of reachable accuracy and insensitivity to most of the distortions [6].

The fourth principle is the strict use of supply voltages that are always symmetric sine signals with few harmonics. By using of three twisted pairs of cable (1 pair for supply, 1 pair for sense, 1 pair for input signal) the outside electric field is minimized.

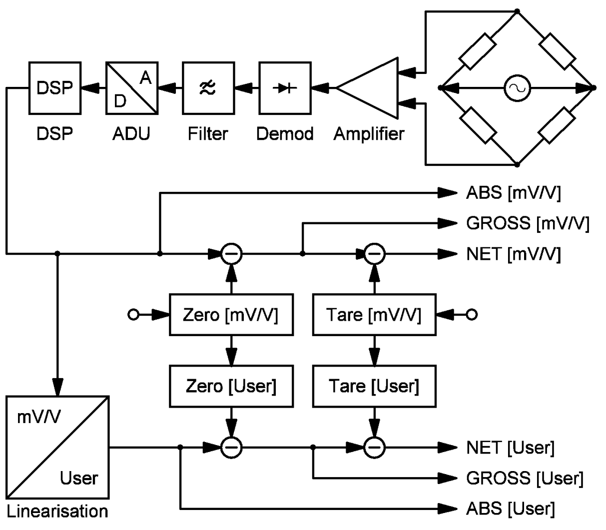

Figure 3 Schematic diagram of DMP41

The block diagram as shown in Figure 3 emphasizes on the details of the data acquisition, including filter realization (in the DSP).

2. OVERALL ACCURACY OF THE MEASURING CHAIN

The major advantage of the DMP41 is that its contribution to the overall uncertainty is very small. If you have an instrument of an accuracy "close to ideal", what could nearly be neglected in the total accuracy:

$$c = \sqrt{a^2 + b^2} \quad (1)$$

Thereof c = total accuracy of measuring chain
a = accuracy of transducer (e.g. force or torque)
b = accuracy of precision instrument

And if b = 0, what is about true, so it leads to

$$c = a \quad (2)$$

This means that considering the effort be put into building up a good transducer, what can be well described, one should choose an amplifier with outstanding accuracy. In developing this instrument series HBM always had this goal in mind. This is one reason why DMP series is widely used as the "reference-instrument".

3. REACHING FOR OPTIMAL FILTER CHARACTERISTICS

High resolution with strain gauge transducers is only reachable with low bandwidth, i.e. slow filters [7]. The input of the amplifier should not produce more noise than the transducer, and the instrument needs digital filters with very high resolution und slow response.

HBM introduced the DMP series as early as 1980. DMP39, the first instrument of the DMP series was developed in close collaboration with the German National Metrology Institute (PTB) in Braunschweig to realize an instrument beyond the demands of industry, exploring the physical limits at that time.

Due to this long history the technical possibilities were limited by the 8–bit architecture of the CPU. Subsequently filters were limited to Bessel filters of low orders at a measuring rate of only 75 Hz.

Now DMP41 – still by the use of the carrier frequency principle- allows the best possible signal to noise ratio with the applied measuring rate of 225 Hz. This gives room for filters of higher order and further optimization.

Low-pass filters are used to suppress unwanted higher frequency interferences that lie above a specific cut-off frequency. Amplitude response, runtime and step response are dependent on the filter characteristics.

With the DMP41 both Butterworth and Bessel characteristics can be chosen.

The differences between Bessel and Butterworth characteristics are shown in figures 4 and 5. The Butterworth characteristic (blue curve in figure 4 & 5) shows linear magnitude response with a steep drop above the cut-off frequency.

On the other hand an overshoot in step response of approx. 10 % occurs. The Bessel characteristic (red curve in figure 3 & 4) shows a step response with very small (<1 %) or even no overshooting. The amplitude response drops less sharply.

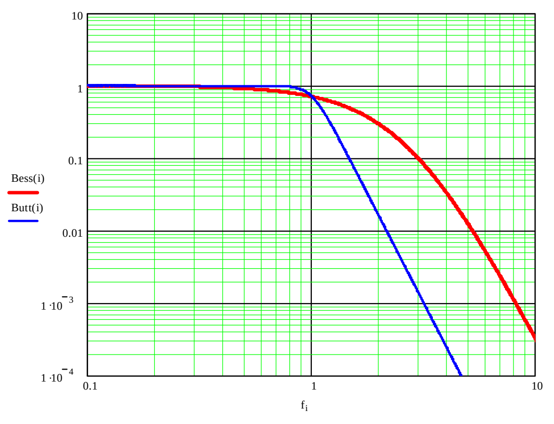

Figure 4. Frequency response of Bessel & Butterworth filters of DMP41

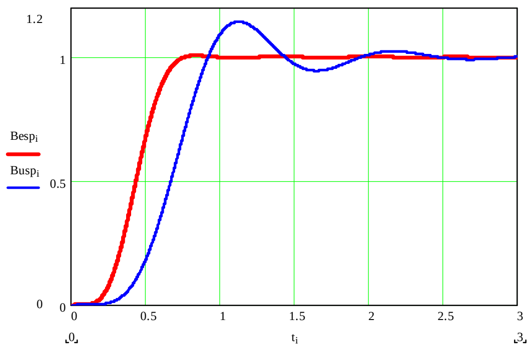

Figure 5. Step response of Bessel and Butterworth filters of DMP41

For the right choice of filters according to specific application cases we can summarize: Butterworth filter fits if e.g. in a material testing machine you have sine shape excitation as the magnitude in the needed range is given most accurate. A Butterworth criterion is to reach a flat frequency response (see blue curve). If we talk Bessel, the design criterion of the filter is the constant group delay. So this filter is best for any kind of unknown (stochastic) signals. Thus in most cases Bessel filters are the best choice.

4. NEW POSSIBILITIES

One difficult task in the development of the new instrument was the requirement for compatibility to its predecessors. But also it is used by different groups or users, such as programmers, system integrators or even manufacturers of load cells at the same time.

The most important customer group are clearly the worldwide national metrology institutes (NMI´s). Many national test institutes, for example the German National Metrology Institute (PTB) as well as the Japanese National Metrology Institute (NIMJ/AIST) use DMP series instruments for their own measurements in many laboratories such as force, torque, pressure and mV/V laboratories. Experiences of our users in laboratories around the globe have been taken into consideration. [8], [9].

However, the DMP41's technical benefits such as accuracy, high resolution or long-term stability are also of importance in the development, production and quality assurance of any kind of strain gauge transducers [10], [11].

However one trend is clearly seen to all kind of applications: the increased importance for multichannel use of the device. DMP41 now offers two to six simultaneous measuring channels. In addition to that, several DMP41 can be switched together by using the master-slave function. By this there are practically no limits to high channel ultra-precision measurement anymore. This will certainly be one of the future trends and it will open up more and more applications in the future.

The graphical user interface (GUI) comes with the main feature of a touch screen and the device can be hundred per cent controlled by remote area. In detail it can be operated by some touch screen or conventionally by functional keys, just as desired.

An important new feature comes with the possibility to update all firmware and operating software quite easily. You may download the setup file from the HBM homepage, insert the USB stick in the PC and execute the Setup file on a Windows computer. Later insert the USB stick into the "USB HOST" socket of DMP41and run the start up routine. This also covers the possibility of implementing new features by the above described way.

Figure 6. Back side of the new instrument DMP41

The new instrument DMP41 additionally provides the possibility the use of TID (Transducer Identification) for unique identification of the transducers connected.

As auxiliary inputs up to 4 temperature channels can be assigned to the two to six strain gage channels and indicated together with them in the display. A possible application is to find out about the temperature gradient in large transducers or also of build-up systems out of 3 or newly even 5 force transducers.

Totally three bridge excitation voltages 2.5 V; 5 V or 10 V can be chosen. In order to compensate nonlinearity of transducers up to 11 linearization points can be directly and easily input to the device.

As the back side of the instrument shows (figure 6) for the input either of each channel DP-15P plug or MS-plug can be chosen. This allows the end user to use nearly all force and torque transducers available in his laboratory, as they all have one of the above plugs attached. It is mandatory to use only one out of the two plugs to connect exactly one transducer to one channels input. If you connect a transducer to each of them, that is of course not the intended use; it will not harm the instrument. Electrically it just switches the two transducers in parallel.

5. LONG TERM STABILITY OVER 30 YEARS

Both the DMP41 and the BN100 are based on an inductive voltage divider. Such dividers are very accurate because their accuracy is only defined by the ratio of the number of windings. This – one can say – "digitally" defined ratio of windings allows relatively small deviations needed for the instrument. Inductive voltage dividers operate most accurately in the frequency range 225 Hz, which namely HBM has chosen for high accuracy frequency amplifier realizations carrier frequency and so also in this instrument. All this makes calibrated inductive voltage divider suitable to be used as a reference even in primary calibration.

This is not only theory, but has been tested and measured from the beginning of HBM´s history in precision instruments [12]. Therefore, since the introduction of the first device of the DMP series, the DMP39 back in 1980, it has proven its outstanding accuracy and long term stability. The long term stability has been monitored since the beginning. It has been monitored for the DMP39 with S/N 001, the first DMP39 ever made together with one of the first units of the calibration device BN100 (S/N 010).

The result is shown in figure 6. Crucial to the long term stability is the so called inductive divider, a main component of all DMP devices. For this reason is realistic to expected, that also DMP41 will show similar long term stability over the next 3 decades.

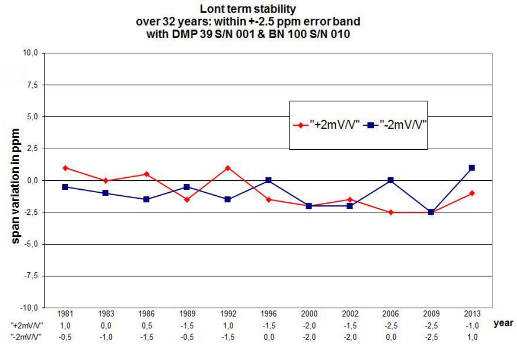

Figure 6. Variation of measured values of long term stability

6. CONCLUSION

Since September 2013- for now about half a year- the new instrument is on sale. The mix of customers shows the global reach out; the demand shows nearly even distribution to all parts of the world. The new DMP41 seems to be the right answer to this global challenge.

So the new DMP41 again shows major improvements compared to its predecessor, the DMP40. Since the introduction of the first device of the DMP series, the DMP39 back in 1980, it has proven its outstanding accuracy and long term stability.

Now the DMP 41 is offering latest features and a much better connectivity and usability. And especially at high-precision comparison measurements of mechanical quantities, DMP41 shows its strengths.

Simultaneous channels, network integration by its state-of-the-art interfaces and the use of sophisticated filter functions are opening totally new possibly with the new instrument.

For inter-comparison programs between National Metrology Institutes for a couple of mainly mechanical quantities the user can even better rely on the instruments excellent performance.

In the future HBM will implement further features for other users in several industrial fields, such as load cell and other transducer manufacturer or automation.

Especially calibration applications and progress in calibration processes, as pointed out in the previous chapters, are the main applications of the instrument.

For this reason this will need our special attention and will be our focus for further development of the instrument in the future. We therefore invite all users of the new instrument to reflect any new demand to us, so we can even better serve their needs.

HBM's DMP series amplifiers have been synonymous with an unprecedented level of precision for decades. HBM has made another milestone with DMP41, the youngest member of the DMP family. By introducing the new instrument we show, that we see a big future in the development of high precision amplifiers and of course also transducers [13], [14].

7. REFERENCES

[1] Schäfer, A.; Kitzing, H. „DMP41- a new chapter of ultra-precision instrument for strain gauge transducers" XX IMEKO World Congress, Busan, Korea, 2012

[2] Kreuzer, M.; „Modern PC-controlled Comparators", Reports in Applied Measurement" /"RAM", year 1999 issue 21, pp. 35-38

[3] Ramm, G.; "Calibration of bridge standards for use in strain-gage measurements"; Reports in Applied Measurement / "RAM" year 1990 Vol. 6, Number 1, pp. 26-30

[4] Hoffmann, Karl; "An Introduction to Measurements using Strain Gauges", Hottinger Baldwin Messtechnik GmbH, Germany, 1989, pp. 145

[5] Kreuzer, M. "High-precision Measuring Technique for strain gauge transducers", Internal publication of Hottinger Baldwin Messtechnik GmbH, Germany, 1999

[6] Kitzing, H., "A solid base for precision strain gauge measurements", Proceedings of XVI. IMEKO World Congress, Vienna, Austria, 2000, pp. 405-408.

[7] Kehrer, R.; Schäfer, A.; „MGC - A revolutionary structured analogue amplifier and its application at a Multi-Channel Body Test Stand"; Proceedings of NVH Symposium´95, Matsushita ; Tokyo, Japan, 1995

[8] Schäfer, A.; "Force, strain and pressure transducers based on foil type strain gauges", Proceedings of Eurosensors XXII conference, Dresden, Germany, October 2008

[9] Ahlefeldt, T.; Koop, L.; Lauterbach, A.; Spehr, C. "Advances in Microphone array measurements in a cryogenic wind tunnel", Institute of Aerodynamics and Flow Technology, German Aerospace Center DLR, BeBeC, Berlin Beam forming conference, February 2010, Germany

[10] Schäfer, A. "Outlook regarding the growing importance of measurement in wind energy", DEWEK 2010, , Bremen, Germany, November 2010

[11] Schäfer, A. "Examples and proposed solutions regarding the growing importance of calibration of high nominal forces" Proceedings of IMEKO 2010 TC3, TC5 and TC22 Conferences, November 2010, Pattaya, , Thailand

[12] Schäfer, A. "Consistently making full use of physical possibilities", HBM hotline.com 1 2013, Darmstadt, Germany; pp.18-19

[13] Schäfer, A. "Analogy observation of force transducers compared to strain and pressure transducers based on foil type strain gauges and the piezoelectric principle", APMF Asia-Pacific Symposium on Measurement of Mass, Force and Torque, Tokyo, Japan, 2009

[14] Schäfer, A. et al. "A new type of transducer for accurate and dynamic pressure measurement up to 15kbar using foil type strain gauges", XVII IMEKO World Congress 2003, Dubrovnik, Croatia, 2003