Basic Information on Acceleration Measurements Using the Data Loggers MSR145, MSR165, MSR175

1 Introduction/Overview

Measuring physical impacts is of great importance in many fields of application in order to obtain information on mechanical loads and the stresses on objects such as goods, merchandise, workpieces, parts etc.

The causative loads, which have arisen as a result of external influences, are to be regarded as largely independent from the examined object. In contrast, the resulting stresses impacting on the object are directly dependent on the examined object and can only be described with reference to the specific object.

An important parameter for evaluating impacting stresses is the dynamic mechanical load, i.e. the chronological sequence of the acceleration impacting on the object. It can be appropriately measured by means of acceleration sensors of different designs and grades, as well as recorded for further analysis, using data memories.

These sensors are, for example, used for transportation monitoring, fault diagnoses and load tests.

2 Table of Contents

3 Definitions

3.1 Acceleration Data Logger

An acceleration data logger is an automatic recording and measuring device, which autonomously records stochastic shocks or vibrations over a specific period of time in the form of unbiased raw data. Once recorded, the shock and vibration data can be retrieved, viewed and analysed.

Figure 1: MSR data logger with integrated acceleration sensor and microSD card

An acceleration data logger is comprised of acceleration sensors, a data storage device, the processor and a power supply. The sensors measure the acceleration currently impacting on themselves, e.g. when subjected to a shock or vibrations. In the process, the individual measurements are taken at specific time intervals and stored together with the respective time value. These measurement frequencies can be arbitrarily chosen between 1 measurement every few seconds and measurement frequencies in the high kHz range (e.g. 5 kHz – 1 measurement every $5{,}000^{-1}$ sec) depending on the sensor type. The higher the measurement frequency, the finer the resolution with which the actual development of the acceleration event is recorded. The disadvantage of high measurement frequencies is that they generate very high volumes of data, meaning that the storage capacity and performance limit of the logger are quickly reached. In particular, continuous measurements as well as processing and storage of the data necessitate high power requirements, which limits the mobile operating times of the logger.

The processor in the data logger processes the measured data and saves it to the storage medium together with the respective measurement periods. This means that the data can be retrieved after measuring has taken place, either directly on the logger or, for instance, via a computer port. Software illustrates the measured data in tables or charts and provides functions for analysing the measured data. A popular analysis method is – besides the viewing and analysing of single acceleration values and their duration – the acceleration-time chart with an application-specific determined DBC (Damage Boundary Curve – see p. 10.).

The shock and vibration data can also be recorded based on events that meet specific criteria. With an event-based measurement, you can specifically record shocks that exceed a critical time period or magnitude. In addition to providing better clarity for long-term measurements, this has the benefit that only relevant events are recorded and therefore energy and storage capacity are used more effectively.

Acceleration data loggers usually use non-volatile storage media to save the measured data. Therefore the measured data is preserved, even if the power supply fails.

[Source: Excerpts from Wikipedia, amended by MSR Electronics GmbH]

For more detailed information on the measurement and evaluation of dynamic mechanical loads, such as transportation monitoring by means of automated recording devices for measuring stochastic shocks, please refer to DIN EN 15433-6, for example.

Acceleration data loggers are, for example, used for the following:

- Monitoring delicate and valuable goods during transportation or storage
- Measuring acceleration in motor vehicles, for example when reconstructing road traffic accidents
- Monitoring production machines that are sensitive to shocks and vibrations during operation
- Determining dynamic loads for and impacting on people
- Determining acceleration for objects on conveyor belts

3.2 Acceleration Measurements

Acceleration usually refers to dynamic signals. This often involves frequencies within the range of 100 Hz … 50 kHz. Acceleration signals can be caused by vibrations and shocks or knocks.

3.2.1 Sensors

An acceleration sensor (also referred to as acceleration meter, accelerometer or g-sensor) is a sensor that measures its own acceleration. This is usually done by determining the force of inertia impacting on a test mass. This is how it can be determined whether acceleration or deceleration takes place. Acceleration sensors belong to the group of inertial sensors.

[Source: Wikipedia “Beschleunigungssensor *(‘Accelerometer’)*”]

To measure acceleration, we use sensors with different measuring principles, usually with piezoelectric sensors or a MEMS (Micro-Electro-Mechanical System) structure. These sensors often weigh only a few grams and have working ranges from just a few g to 1,000 g or more.

3.2.2 Positioning

In order to determine the position of the object (upright, horizontal, on the side and all positions in between), three acceleration sensors are required. Preferably they are located perpendicular to each other along axes x, y and z of the object; they measure the effectively static, ordinary acceleration of gravity along the axis. If the object changes its position, the percentages of the acceleration of gravity per axis change.

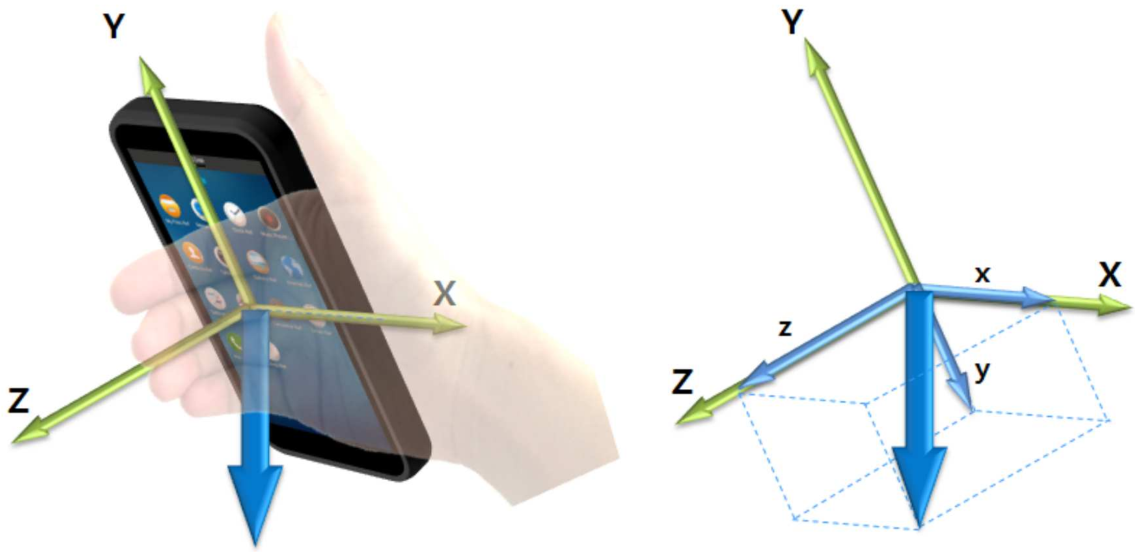

Figure 2: Axes when positioning

3.2.3 Vibration

[Source: Wikipedia and MSR Electronics GmbH]

Vibrations are periodic (mechanical) oscillations of matter and objects, usually at medium to high frequencies and low amplitudes. The vibrations are described by their frequency. In addition, the maximum accelerations the device is subjected to are specified. They are usually specified as a multiple of the acceleration of gravity. At low frequencies the vibration is not defined by means of the acceleration but the amplitude (deflection) of the object. Depending on the frequency range of the vibration, the occurrence of mechanical vibrations over longer periods of time may result in material fatigue.

For example, particularly strong vibrations impact on compressors and mobile work machines or during very “bumpy” transport. The acceleration data logger measures and records vibrations as a chronological sequence of individual g-values. The time between the individual measured values is determined by the measurement frequency (number of measurements per time unit).

Please note:

In order to be able to correctly record vibrations by means of acceleration sensors, we must select appropriately high measurement frequencies that are suitable for the vibration. Otherwise, if there are high vibration frequencies on the measuring object, it is possible that the vibration is mapped inadequately (see figure 3 and subsection).

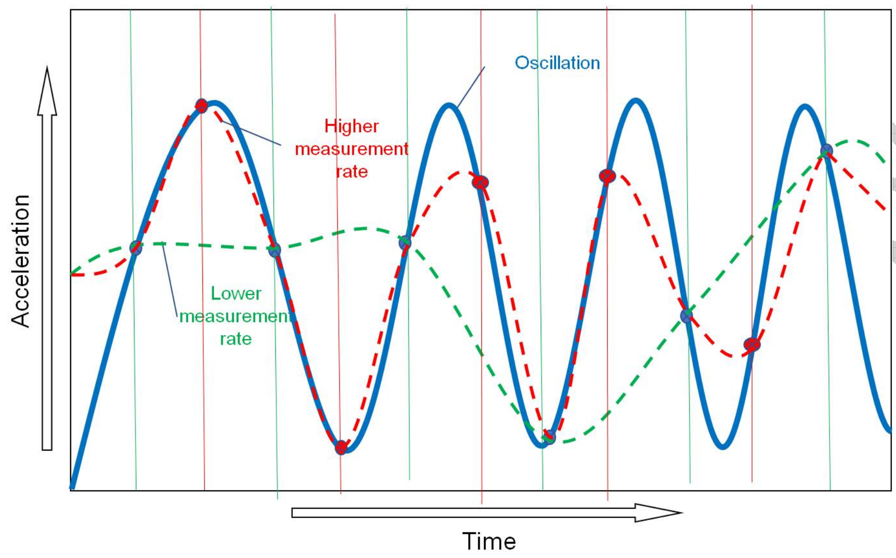

Figure 3: Oscillations – resolution at a lower and higher measurement rate

3.2.4 Jolt/Shock

If an object is subjected to individual major changes of velocity (accelerations) of short duration, this is referred to as a mechanical shock. This happens, for example, during car accidents or after a fall, when the object hits the ground and is decelerated abruptly.

Shocks are specified as a multiple of the acceleration of gravity [g=9.81m/s²]. Furthermore, the duration of impact of this load is stated. Standard values measure up to several hundred g for a few milliseconds.

Shocks are characterised by the following:

- Acceleration axes x, y and z of the three measuring directions that are perpendicular to each other
- Acceleration values a_x, a_y and a_z in the direction of the acceleration axes
- Acceleration peaks for the x, y and z axes or the space vector
- Main axis xyz(max) – axis with the greatest acceleration peak $\hat{\boldsymbol{a}}$ (point 1 on fig.4)
- Acceleration value a_R of the randomly aligned space vector of the acceleration of the shock event

$$a_R = \sqrt{a_x^2 + a_y^2 + a_z^2}$$

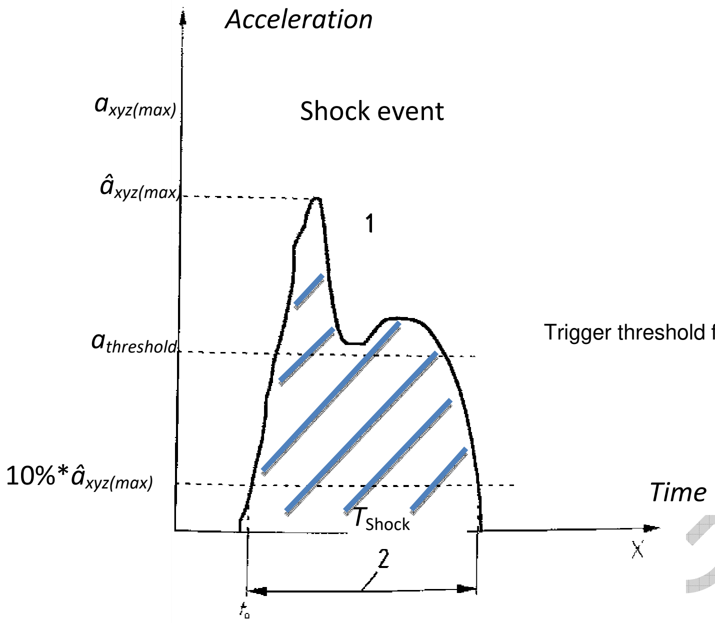

Figure 4: Typical sequence of a shock event

[Based on the source: DIN EN 15433-6:2008-02]

Examples of external shocks impacting on the load during transport:
[Source: Load-security information system (LIS), BAM, effective: June 2003]

Means of transport	**Horizontal acceleration**			**Vertical acceleration**	
	In direction of travel	Opposite to the direction of travel	Transverse to the direction of travel	Up	Down
Road vehicles (lorries)	0.8 g	0.5 g	0.5 g	n.s.	1.0 g
Rail vehicles	4.0 g	1.0 g	0.5 g	0.3 g	n.s.
Rail vehicles	1.0 g	1.0 g	0.5 g	0.3 g	n.s.
Sea vessel	0.4 g	0.4 g	0.8 g	n.s.	n.s.

Chart: maximum acceleration on transport carriers.

[Source: DIN EN 15433-6:2008-02 and MSR Electronics GmbH]

Transport mode	**Working range [m/s²]**	**Shock duration [ms]**	**Frequencies [Hz]**
Road, e.g. pothole	100	5	approx. 10 to 15
Rail, e.g. shunting shocks	100	20	approx. 120

As every load/object responds in a specific way to impact, as a general rule, both the mechanical stress and the actual impact on the object should be determined experimentally by means of acceleration sensors, (preferably) during real stress (e.g. transport).

In the event of a shock, knowledge of the acceleration peak is often not sufficient; in fact, the respective duration of the shock is equally relevant, as it can be used to determine the intensity of the shock, either directly or in comparison with other shocks to the object.

In the figure 4, the ***intensity*** (also: “magnitude”, “pulse”, “energy”) of the shock is indicated by the area (shaded with blue color) below the curve above the time axis. A large area signifies an intense shock, which usually indicates a shock lasting a “long” time with high acceleration values.

Background:

The time integral of the acceleration within the shock duration T_{Shock} corresponds to the object’s change of velocity related to the shock event:

$$\Delta v = \int_{t0}^{t0+TShock} a_{xyz(max)} \, dt$$

The object velocity v can be found in the formulae for the pulse I

$$I = Mass\ m * v$$

and for the kinetic energy E

$$E = \frac{m}{2} v^2$$

and is therefore the variable element in the specific object shock.

Please note:

Two shocks with the same area may have a different impact on the object as the absolute values of the shock duration and acceleration always determine the impact on the object as well.

3.2.4.1 Intensity & pulse duration – assistance in ranking shock events

The maximum acceleration value in a shock event is, as described, basically a helpful value for assessing a shock. In particular within the context of longer measurements, e.g. when monitoring transport, this value is, however, generally not sufficient in order to compare various shock events with one another (see above).

It is therefore expedient to enable multiple shock events recorded to be ranked in a series of measurements of pulse **intensity** values **(Intensity over Threshold – IoT (max.)** or **IoT (total)** and the **pulse duration – Time over Threshold – ToT (max)** or **ToT (total),** besides the pure maximum acceleration values, through values calculated for the intensity.

Note:

These options exist, for example, in the MSR software for the MSR165 and MSR175 data loggers (ShockViewer/Dashboard, etc.). With the aid of the values for intensity (IoT) and pulse duration (ToT), it is possible to individually sort the shock events according to the most expedient filtering option for the application, in order to, in this way, be able to focus on the most serious events in the analysis of the series of measurements.

3.2.4.2 Intensity over Threshold – IoT (max) and IoT (total)

The intensity of the shock event is ascertained in the respective MSR PC software (e.g. MSR ShockViewer). In this respect, the area between the g-value curve of the individual shock event and the lower threshold set for the g-value is integrated over the time and added up for the entire event.

The g-value curve itself is always positive, as values of the resulting g-value space vector are contemplated (see above). The intensity is specified without a dimension. It is to be kept in mind that the intensity ascertained here does **not** correspond to the actual total energy of the individual shock occurring, as only the area between the first and last measuring points of the amplitude of the resulting total g-value above the threshold is contemplated, in other words the proportion of energy between 1 g and the threshold is not taken into account (see Fig. 5). This perspective, however, offers, for the detailed analysis, the opportunity to compare individual shock events in a series of measurements with one another in a simple way above the threshold laid down at the beginning of the series of measurements, and make a pre-selection or set a display filter.

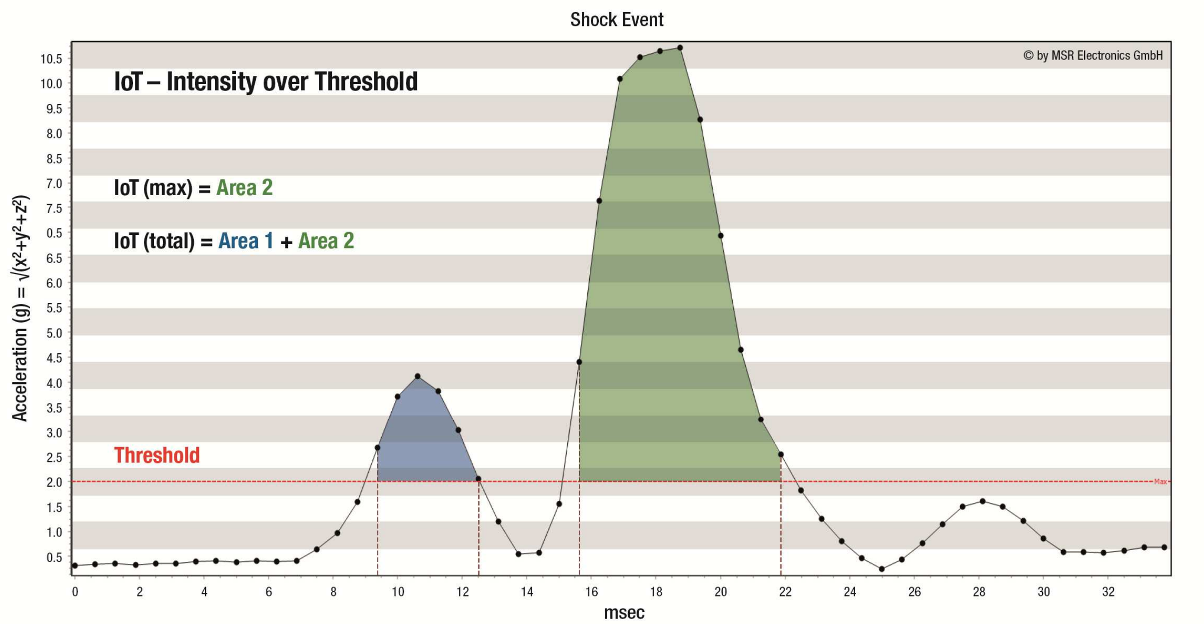

Fig. 5: Determining the event intensity

The sum of all areas, viz. Area 1 + Area 2 +…+ Area n yields the intensity IoT (total) of the overall shock event.

Note:

A shock event is limited, in the MSR analysis software, to a maximum duration of approx. 200 ms, and after that a new event may seamlessly begin. Consequently, high ToT (total) values for shock events may indicate agitated or vibrational loads on the object).

The value for **IoT (max)** corresponds to the largest individual intensity area n of a shock event, which is Area 2 in Fig. 5. High values for IoT (max) are mostly of particular interest, as they may be responsible for damaging impact on the object observed, even if the entire intensity of the event is, in total, comparatively small

3.2.4.3 Time over Threshold – ToT (max) and ToT (total)

For each shock event recorded, the pulse durations **(Time over Threshold – ToT (total or max)** in msec) in which the shock amplitude has exceeded the pre-set g-value threshold (from the MSR data logger PC configurator) and subsequently fallen short of it again are ascertained. Should this repeatedly be the case in a given shock event (see Fig. 6), the durations are added to the - ToT (total).

It is to be kept in mind that the pulse duration ascertained here between the first and last measuring points of the amplitude of the resulting total g-value above the threshold is obtained (Fig. 6).

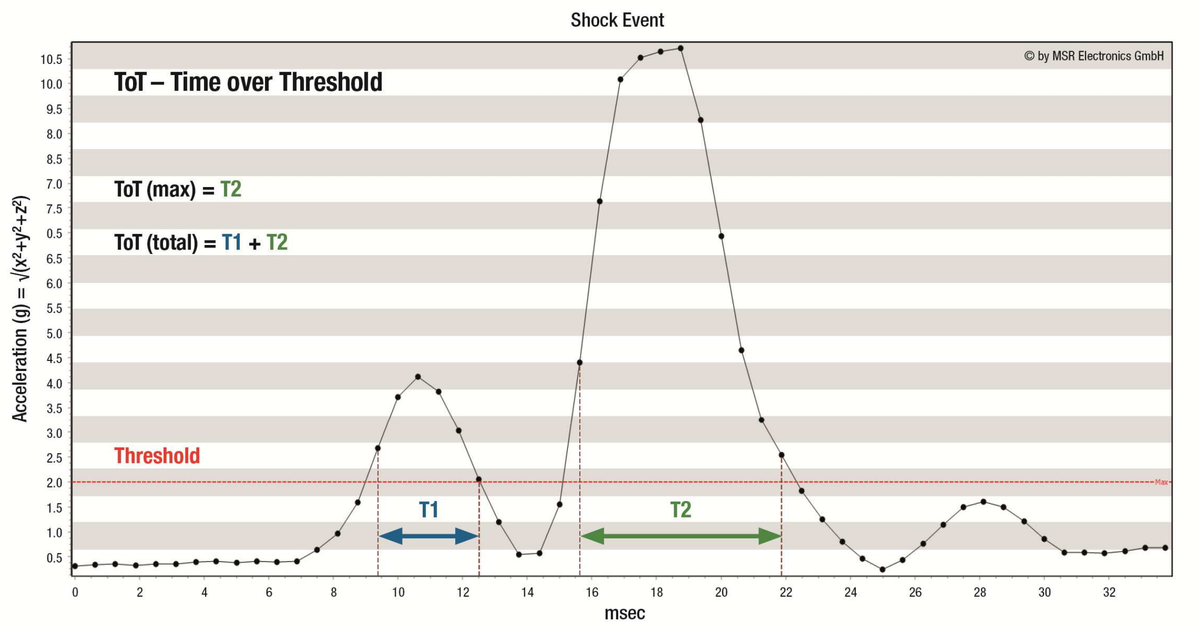

Fig. 6: Ascertaining the Time over Threshold ToT

The sum of all times T1+T2+…+Tn, by which the value of the aggregate acceleration vector exceeds the threshold set during the event yields the ToT (total) of the shock event concerned (see Fig. 6).

The value of the **ToT (max)** corresponds to the longest time interval of an individual ToT (total), which is T2 in Fig. 6.

High values for ToT (max), viz. relatively long exposure times of the undesired g-load, are mostly of particular interest, as they may be responsible for damaging impact on the object observed, even if the ToT (total) of the shock event is, in total, comparatively small.

Note:

A shock event is limited, in the MSR evaluation software, to a maximum duration of approx. 200 ms, and after that a new event may seamlessly begin. Consequently, high ToT (total) values for shock events may indicate agitated or vibrational loads on the object)

3.2.5 Damage Boundary Curve

[Source: Wikipedia and MSR Electronics GmbH]

The damage boundary curve (DBC) is a method used to detect damage to an object caused by shocks. The DBC divides a shock chart into two areas, a non-critical and a critical shock area. A shock that touches the critical area may have a destructive effect on the object.

Theory:

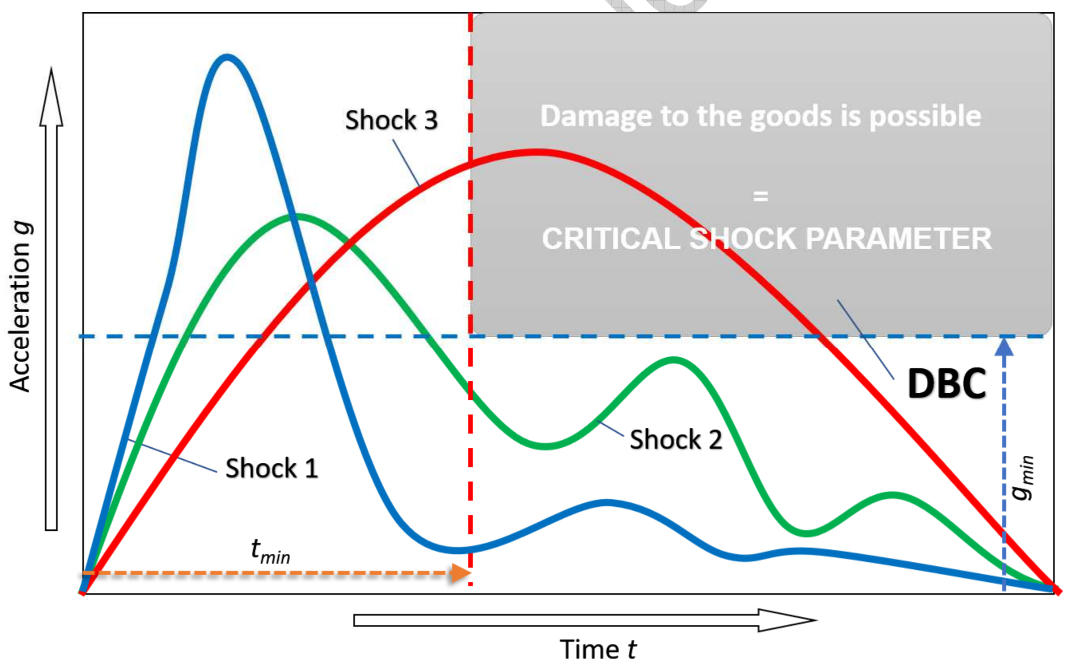

Figure 7: Shock chart with a critical, potentially damaging shock

For a shock to become critical, it must have a certain minimum acceleration g_{min}*(shock) and* a minimum duration t_{min}*(shock)*. What is critical for a specific object differs from object to object, and depends on its respective state. Depending on how sensitively an object responds to shocks, the DBC in the chart will present differently. If the chart contains a shock that touches the critical area, we have to expect damage to the object (shock 3 in fig. 7).

Therefore, in order to facilitate an appropriate classification of the loads impacting on an object, we must specify the critical conditions for the minimum duration and minimum acceleration. If necessary, these combinations must be determined experimentally in the run-up. Test specifications for this can, for example, be found in DIN EN 15433 et seq.

Practice:

Shock charts with DBC are used, for example, in order to examine delicate and valuable goods transports, load impact on objects in production facilities or load impacts on production machines during operation. To this end, acceleration data loggers record shocks that impact on the object to be examined. The recordings are presented in a shock chart. Depending on the design of the loggers, only shocks relevant to the DBC are recorded or, within the scope of the analysis of all recorded data, the lower limits for acceleration and duration can be specified for the analysis.

In regard to the use of MSR data loggers, this means that a DBC evaluation can be performed with the aid of the individually adjustable thresholds for the g-values to be recorded/that have been recorded and the minimum duration for the exposure time t_{min} (impact) = ToT (max). An additional contemplation of the intensities of the shock events using the values for IoT (max) may then expediently support the DBC evaluation.

3.2.6 Measurement Frequency/Sampling Rate/Fast Peak

An acceleration measurement is determined by the working range of the acceleration sensor and the possible or applied measurement frequency (also referred to as sampling rate) for the measurement. The working range describes the maximum g-values that can be recorded (e.g. ± 200 g). This range is specified for each sensor type, depending on its design. Depending on the measuring task, an acceleration sensor with the respective working range must be selected.

The measurement frequency or sampling rate describes the number of g-value measurements per time unit (usually per second – in the unit of Hz). The measurement frequency predetermines the accuracy of recording the acceleration event. When detecting changes of position, a relatively low measurement frequency is sufficient as the processes involved are often slow. Shocks and vibrations, however, require as high a measurement frequency as possible in order to properly map the g-value developments of the event. The higher the measurement rate, the more accurately the actual development is mapped.

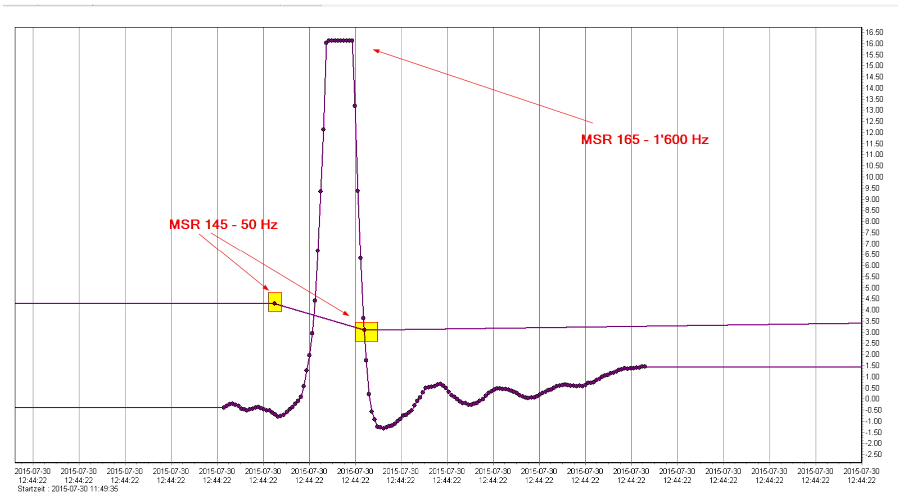

Figure 8: Resolution of a shock event with a low and high measurement frequency [Hz]

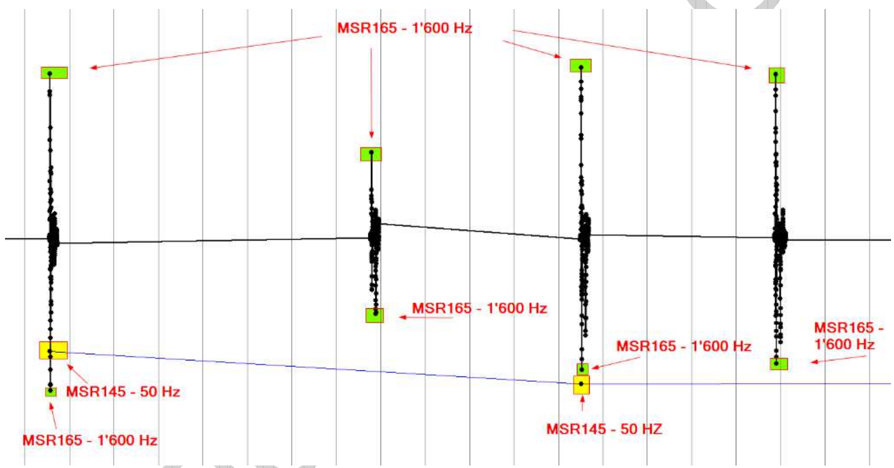

Figure 9: Resolution of several shock events with a low and high measurement frequency [Hz]

In figures 8 and 9 we can see that at a low measurement frequency (50 Hz), information on the development and the peak acceleration values of the shock event(s) are recorded poorly (figure 8) or not at all (see figure 9). This is not the case at a high measurement frequency (1,600 Hz). Development and peak values are mapped better and accordingly, they can be analysed in a meaningful manner (*please note:* the peak values mapped in figure 8 are limited to 16 g due to the logger design).

However, the disadvantage of a high measurement frequency is that, if measurements are taken continuously, this generates an accordingly large data volume, which quickly depletes the memory capacity of the acceleration data logger and therefore significantly limits its period of application. In particular if the focus of the measurement task is not on short-term shock and vibration analyses, but on long-term monitoring, e.g. during transport processes, this is undesirable. Here it is only the event causing damage that is supposed to be recorded as accurately as possible.

In order to implement this task as effectively as possible, generally the following approaches are widely used:

1. Only events that exceed a specific pre-set g-value („Threshold = adxl_level_on“ in fig. 10) and minimum shock duration (ToT) are recorded and stored. Here it is meaningful to also store a few g-values that are chronologically before and after the event (e.g. 32 measured values) so as to be able to analyse the data for the entire event (automatically occurs in this way with MSR data loggers). This approach saves memory capacity as only the relevant events are stored. However, this requires a good knowledge of the relevant events so as not to lose any interesting events in the recording as a result of the pre-setting.

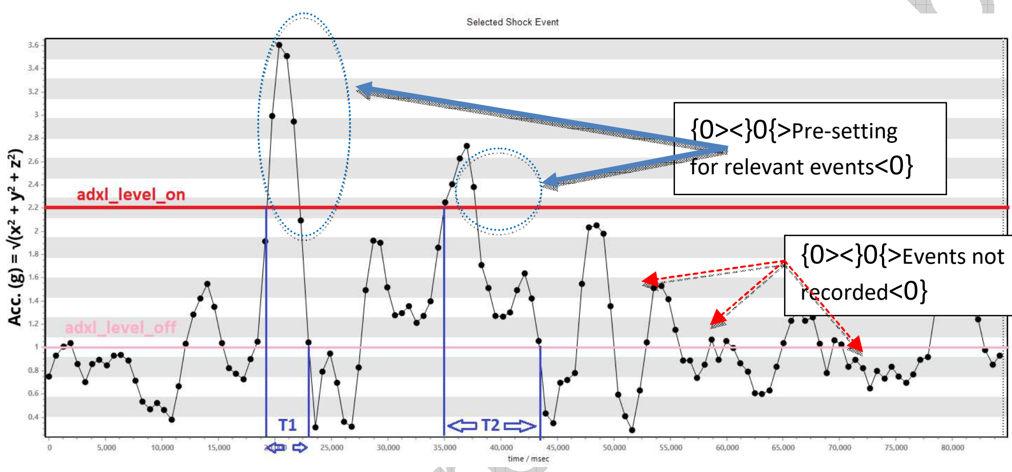

Figure 10: Relevant events with pre-set g-value threshold

Note on Fig. 10:

Currently, only one threshold can be set for the g-value, which is “adxl_level_on”, and “adxl_level_off”

2. With the “fast peak” feature, the measurement frequency is pre-set, e.g. to 1 kHz. Then an arbitrary measurement interval is selected, at the end of which the maximum g-value for acceleration measured during the interval is stored. The measurement interval (=storage rate) can, for example, be set from “maximum of 50 storage actions per second” through to “store once every 12 hours”.

   For example, if a storage rate of 1/s is selected, the acceleration is sampled at 1 kHz and the maximum value (= peak value of the last 1,000 measured values) is stored once per second.

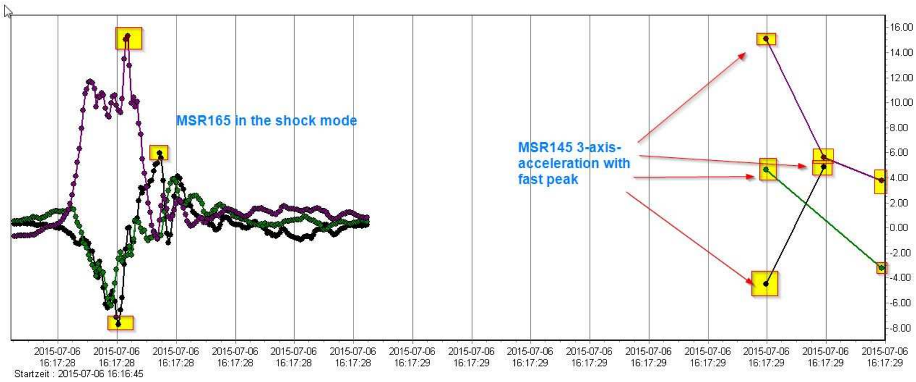

Figure 11: Comparison of high measurement frequency vs. fast peak – peak values of the event

Figure 11 shows very well that, with respect to the peak values of the event, the fast peak method returns good results. However, the development of the relevant shock event is not recorded and is consequently lost. In applications, where only the peak values of the load and its direction are of importance, this method is well suited for preserving the storage capacity without running the risk of failing to record relevant events due to unfavourably pre-set thresholds. However, peak g-values that are not of interest are also continuously recorded during the set time interval.

4 MSR145, MSR165 and MSR175 Data Loggers

The range of a data logger must always be specified with respect to the required measurements.

In order to determine acceleration values, which occur for example during transportation on the loading platform of a vehicle, a relatively small working range is generally sufficient. To monitor a pallet shipment, i.e. to measure vibration and minor shocks (< ±15 g), the MSR145 mini data logger is therefore generally very well suited for this task. In particular the “fast peak” model is used in this segment as the peak values of the shock are recorded at a measurement frequency of 1 kHz over the entire measurement period.

For short, more intense shocks, e.g. 75 g with 8 ms, which may occur during individual shipments, the MSR165 and MSR175 data loggers, which are recommended specifically for transportation monitoring, are more superior to the universal MSR145. With 1600/s (± 15 %) respectively up to 6400/s, the MSR165 and MSR175 allow the user to take a significantly higher number of measurements than the MSR145 (50/s); therefore, transportation stresses can be identified with a far greater resolution. The memory of the MSR165 is capable of storing 2 million measured values, which is sufficient for recording more than 10,000 shocks; (MSR175: 1,000 shocks), the memory capacity of the MSR165 can be extended to more than 1 billion measured values by using a microSD card. Bonus feature: 32 measured values are stored before the actual event. Shock monitoring using the MSR165 or the MSR175 is also possible up to a maximum of ±15 g or up to ±200 g.

Besides the MSR165, in particular the MSR175 transport data logger, specially designed for monitoring or recording shock, offers an efficient way to document transport damage.

Data Logger Type	Working Range	Measurement Frequency	Storage Rate
MSR145	**±15 g; -20...+65 °C**	50/s to every 12 h	50/s to every 12 h
MSR145 *Fast Peak*	**±15 g; -20...+65 °C**	1000/s (fast peak) 50/s to every 12 h	50/s to every 12 h
MSR165 *Shock Mode*	**±15 g; -20...+65 °C** **±200 g; -20...+65 °C**	1600/s to 100/s	1600/s to 100/s (only the relevant events)
MSR165 *Vibration Mode*	**±15 g; -20...+65 °C** **±200 g; -20...+65 °C**	1600/s to every 12 h	1600/s to every 12 h
MSR175	**±15 g; -20...+65 °C**	1600/s	1600/s
	±200 g; -20...+65 °C	3200/s 6400/s	3200/s 6400/s

Table: Measurement of 3-axis acceleration using the MSR145, MSR165 and MSR175 data loggers

5 Outlook

Notes and explanations on the deployment and in regard to the application of the MSR145, MSR165 and MSR175 shock and vibration loggers mentioned, as well as the options for processing the entire data in a series of measurements with the aid of MSR's own software analysis tools (MSR Dashboard, MSR ShockViewer, etc.), can be found on the MSR website:

www.msr.ch

For example, the following topics can be found there, under the menu item "**Support**".

- Frequently Asked Questions (FAQ)
- Download MSR datasheets
- Download user manuals
- MSR PC software
- MSR Firmware updates
- MSR DataLogger App
- Free e-mail newsletter

As an aid in the application of, for example, the MSR ShockViewer, you will find a series of **video tutorials** on the **YouTube channel "MSR Electronics GmbH"**, as well as on our website msr.ch:

msr.ch -> Support -> MSR PC Software -> MSR ShockViewer ->
„MSR ShockViewer video tutorials"

Please note that this Statement of Basic Information is not a substitute for the professional advice provided by an MSR sales representative; furthermore, all information is subject to change, errors excepted. For a personal consultation, please contact one of the 90 MSR sales partners in over 50 countries around the world: https://www.msr.ch/en/contact/

We wish you much success with your measuring tasks.

MSR Electronics GmbH

