

# Qualification of standard MEMS accelerometers for high end applications

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**Abstract-** Many customers using accelerometers for advanced application (i.e. Inertia or tilt measurements for military but also civilian domains) are aggressively looking for cost reduction opportunities in their program. One of the possibilities is to replace dedicated and expensive traditional sensors by standard products, available off the shelf from a supplier.

In this sense, MEMS accelerometers are ideal candidates and more and more selected for traditional but also newly emerging applications.

Anyway, once a product has been selected, it is generally becoming obvious that minimum requirements can be much more stringent than existing level of qualification. Large investments must be invested by the supplier to demonstrate compliance.

The goal of this paper is to present some critical parameters of such a qualification and the level of performance obtained by medium / high end MEMS capacitive accelerometers in production (typ. MS8000 series from Colibrys).

Finally, we will demonstrate how these products benefit from this synergy to continuously present improved performances and better serve the market place.

## I. INTRODUCTION

The evolution and improvement of performances of standard MEMS accelerometers available from the shelf from various suppliers (COTS: commercial of the shelf), combined with an increasing pressure on cost from the market side, are at the origin of an interesting migration process of many companies from traditional custom, high end and expensive products toward new standard and lower costs solutions.

This is especially true for automotive and aerospace & defence business where MEMS accelerometers impose themselves despite the inertia and protectionism of these markets. Today, standard MEMS accelerometers are more and more used in many applications and regularly gaining market shares.

Anyway, when looking carefully at the qualification process, the path to production is not obvious for manufacturer and suppliers of standard products and major upfront investments are necessary to be able to demonstrate the full compatibility of the product to the requirements.

## II. EMERGENCE OF MEMS TECHNOLOGY

MEMS products have imposed themselves over year in the automotive market offering the right specification and the right price for very demanding applications. Today, even if MEMS accelerometers are not yet able to achieve the same level of specifications as traditional micro-mechanical products (i.e. quartz vibrating structures), they are gaining more and more market shares in the aerospace and defence market but also in the energy (oil & gas), the industrial and in the instrumentation markets. To respond to these markets demand, only few companies like Colibrys, have already in place a very robust control of the MEMS technology and the adequate manufacturing tool, allowing them to produce high end MEMS accelerometers in high quantities, without concessions on specification.

The main reasons for the success of MEMS are certainly the ideal combination between technical capabilities and economical aspects but one explanation is also to be found in the reputation and increasing maturity level of this technology in term of qualification.

This maturity has largely been induced by stringent requirements put on the standard products by the market side to fulfil the need of specific high end programs.

## III. SELECTION PROCESS OF A STANDARD PRODUCT FOR ADVANCED APPLICATIONS

Since beginning of this new millennium, many companies, extensively using accelerometers, have been forced to migrate from traditional high end and expensive solutions towards standard solutions. The main drive for this transfer of technology was largely an economical aspect but in some cases also, the need for more robust technical solutions (harsh environment, size and weight, power consumption...). Some major companies also took the opportunity to reduce their own cost by abandoning their very expensive in house manufacturing capabilities and by subcontracting this manufacturing process to specialized MEMS manufacturers.

The selection of an external supplier can be divided in three major steps:

- **Theoretical analysis of published specifications and datasheet comparison**

→ This operation can be quite chaotic and in any case is a very difficult process. Even if standards exist, they are not formally applied and can't be used as a common basis for an objective comparison.

Every supplier is trying to promote his product by presenting the best facet of it, avoiding critical parameters or difficult specifications, trying to make the product as attractive as possible. The vibration rectification error (VRE) or stability of the products are typical examples.

- **Measurements and basic comparative qualification of sensors**

→ The trend for the customer is to get the better feeling of the product capability with minimum investment. Indeed, the technical analysis of a sensor is an expensive and time consuming process. Electronic and physical interfaces are different and require specific holders or PCB. The advantage of this qualification step is the possibility to get an objective comparison of critical aspects of the products with regard to the requirements of the final application.

- **Analysis of the maturity and viability of the potential supplier**

→ This last point must not be underestimated and is certainly a key factor for the selection of a supplier. Indeed, the strategic value of programs or products in which standard accelerometers will be incorporated is such that the user will only rely on robust, viable and focused companies, capable to demonstrate their ability to continuously produce the right product with the right specification, on time and generally over a long period of time.

#### IV. QUALIFICATION STATUS OF STANDARD PRODUCTS

The maturity of development and qualification level of a standard product is variable from one company to the other and largely depends on the background of the company itself (culture of company, market of interest, technical skills, manufacturing tool...)

At Colibrys, a very robust design review process based on 5 steps is over helming all development and insures a good initial qualification level. These five steps are:

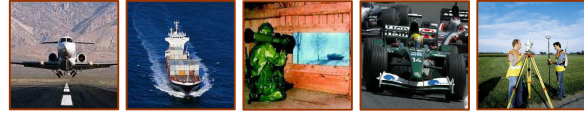
- Phase 0 (DR0) Product request
- Phase 1 (DR1) Project proposal
- Phase 2 (DR2) Demonstration of feasibility
- Phase 3 (DR3) Product development
- Phase 4 (DR4) Product qualification
- Phase 5 (DR5) Qualification for volume production

The standard Colibrys accelerometers resulting from this initial qualification and available in relative large quantities, directly from the shelf, are offering quite a high level of qualification. One of the key reasons for this maturity has to be found in the fact that all products are developed in the manufacturing environment, using the production tools and existing qualified processes already at the early phase of the

development. This is certainly a major advantage compared to companies that qualify initial products issued from an engineering laboratory and which then have to fully transfer it in a manufacturing environment.

All standard specifications of the Colibrys products, demonstrated either by qualification or fully tested (ATP) have been selected based on the key requirements of the three possible domains of applications for MEMS accelerometers; Inertia, Tilt & Inclination, Seismic & Vibration.

Inertia :



Tilt & Inclination:



Seismic & Vibration :



The merge of these requirements is the guideline for all qualification test plans (QTP) and qualifications campaign of all our accelerometers.

#### V. REVIEW OF KEY ASPECTS OF THE SPECIFICATION OF STANDARD ACCELEROMETERS

When analyzing the standard specification of a product, some parameters of the specification are easy to determine as other critical one are rarely available:

##### Performances

Easy to find: Range, scale factor or sensitivity, global temperature sensitivity, non linearity, frequency response, output noise density

Rarely available: Stability of bias, scale factor, non linearity, hysteresis, misalignment, vibration rectification error...

##### Environmental

Easy to find: Operating temperature, shock survivability, size and weight

Rarely available: Reliability, vibration susceptibility, shock resistance (max shock without impact on specification), recovery after shock, ESD and RF susceptibility...

##### Electrical

Easy to find: Supply voltage, current consumption, output signal

Rarely available: Switch on conditions, limitations on power supply (brown-out)

To get a complete and precise understanding of a product, this technical analysis is of course completed by a commercial analysis where key issues like pricing but also quality systems in place, security of delivery, company and product perenity or export license issues have to be considered.

#### VI. QUALIFICATION OF A STANDARD PRODUCT FOR ADVANCED APPLICATIONS

Even if all this information is available, a simple and direct comparison between different products from different suppliers is not obvious. Measurement conditions or signal conditioning can be either different or simply not known: i.e. temperature used for the qualification, difference in temperature ranges (temperature coefficients), difference or lack of definitions (bias stability, shock resistance...), different units for the measurements (voltage, current, frequencies or g).

To consolidate the understanding of the real product capabilities, this initial soft selection is generally completed by real measurements, performed by the customer on key requirements of the program or application. Some typical examples are presented hereafter:

- For inertia type applications, measurements of short term stability, switch off / switch on stability and vibration rectification error are generally performed.
- In case of utilization under extreme conditions, stability after gun hard shocks or extreme vibrations can be tested.
- For tilt & inclination applications, resolution and temperature sensitivity will certainly be analyzed
- For seismic measurements, noise and resolution are considered

At that stage, even if the customer has only been able to partially fill its conformity matrix of the product with regard to the final application requirement, he is in a position to select the best fit for its requirements.

Note that technical performances are generally mandatory but are not necessarily the main factor for the selection of a supplier.

Pricing are confirmed, contract is signed so, as a supplier, you are ready to start production and deliveries. Anyway, you still have to demonstrate the real conformity of your product with the final customer specification and generally, existing datasheet and corresponding qualification becomes the basis of a much more complete requirement. The final purchasing spec includes a much larger set of requirements compared to current qualification status: Typical examples encountered in practical cases are presented hereafter:

- Complementary applicable documents like IEEE or MIL standard specifications (guide and test procedures, sensor terminology, quality requirements, specifications

for hybrid microcircuits ...) can be attached to the specification

- The validity of the standard specifications has to be demonstrated over the full environment requirements (temperature, vibration, shock). This request sounds obvious but some measurements are very specific and difficult to perform. Some examples are given hereafter:
  - Validity of the frequency and phase response over the full temperature range
  - Robust turn on (maximum delay, stability...) in any temperature condition.
  - Shock survivability and shock resistance to be demonstrated at the extreme temperatures. This can be relatively easy for standard shocks but more difficult to perform for gun hard type shocks (typ. 20'000g).
  - Noise, non linearity, vibration rectification error in all environmental conditions
  - VRE under dynamic conditions
- Precise definitions are confirmed for some specifications. This is mainly the case for the various stability requirements:
  - Bias and scale factor stability which can be a complex combination of warm-up stability, temperature stability, environmental stability, ageing...
  - Misalignment stability
  - Scale factor linearity stability
  - Hysteresis stability
- New constraints can be put on the product to fulfil some specific requirements of the application.
  - Time to full performance
  - Brown-out protection
  - Susceptibility to RF or radiations
- Administrative requirements are generally gathered in standard terms and conditions of purchase or in a specific contract.
  - Delivery conditions
  - Perenity of the products
  - Conditions on deliveries
  - Limit of responsibilities

Considering the complexity of the process, a precise procedure and efficient management is mandatory to control the qualification time and qualification cost. At Colibrys, we have a precise procedure in place which can be summarized as follow:

- Establishment of a precise Qualification Test Plan (QTP), with:
  - description of the test method
  - definition of the type of equipments to be used
  - clear description of the specification limit
  - selection of the product to qualify and the sampling size
  - pass / fail criteria
- Qualification report with a clear link to the QTP
- Final qualification status to be signed by supplier and customer and required to free production. This

document includes a clear production test plan, describing which parameters are fully tested (ATP) and which parameters are demonstrated by qualification.

In principle, this last set of parameters, demonstrated by qualification only, will have to be confirmed on a regular basis and this process is described in a continuity quality plan.

Every successive qualification of our COTS (commercial of the shelf) products for high end applications is participating to the continuous improvement of the complete product family. As long as the manufacturing cost and selling price is not affected, benefits from the qualification are largely retrofitted in our standard datasheet allowing all our customers to prevail from these improvements,

## VII. CONCLUSION

The market trend for high end applications is clearly to use more and more standard products, ideally available from the shelf (COTS). Anyway, these applications and programs are heavily driven the qualification level of OEM products like MEMS accelerometers, pushing the suppliers to offer better and better products.

Colibrys has successfully experienced this process many time and latest success is the qualification of it's MS8000 series accelerometers for a major anti-tank European program.

Even if investments are important, the outcome of this process is extremely positive and beneficial for all the customer base of the company. MEMS capacitive accelerometers in particular but also the rest of all our products in general (MEMS for optical applications, telecom, RF or industrial application) benefit from this experience and acquire a unique level of maturity, making them ideal candidates for increasing number of markets, customers and applications.