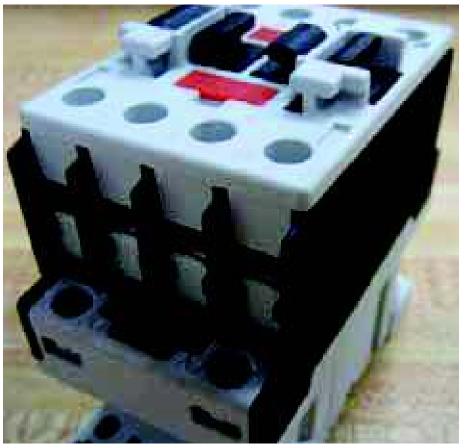
How Geometrical Dimensioning & Tolerancing influence the performances of an electromechanical contactor



Lovato Electric has been a prestigious Italian company operating in the electromechanical and electronic components market for more than 90 years. Its wide catalog includes magneto-electric switches, contactors, sensors, digital multi-meters, soft-starters, relays, automatic power factor correctors and other devices. Top quality, reliability and product variety make Lovato Electric a star player in the world market. Company success is gained through constant valorization of internal competences and parallel effective collaboration with customers and suppliers.
In a past engineering service, EnginSoft was requested by Lovato Electric to investigate how the operation of an electromechanical contactor is influenced by dimensional and geometrical tolerances of its components (GD&T analysis). Electromechanical contactors constitute a relevant fraction of Lovato Electric production, so that the topic was perceived as of primary importance.
An electromechanical contactor is a compact device including an electromagnetic actuator mechanically connected to a set of contacts. When the command signal (a low power current) activates the internal inductor, a piston moves and change the connected contact status. Typically, this device is used to break a power circuit from changes location, without manually accessing the switch. The contactor is composed by both plastic and metallic components held together by snapfeatures and screws. Plastic parts are manufactured by injection molding process, while metallic parts are manufactured by cold forming of sheets. The contactor works reliably if the assembly process creates both precise clearances and precise interferences between parts, where they are necessary.
Indeed, these geometrical conditions return stable coupling of fixed parts, adequate freedom of moving parts and appropriate room to house electrical parts. For simplicity, we will call "functioning measurements" all those the contactor dimensions from which its reliable operation depends. In other words, if one or more functioning measurements is not comprised between assigned limits, the contactor assembly does not work properly and has to be rejected.
Generally speaking, overall dimensions (including the functioning measurements) of a multi-part assembly depend on how both surfaces and edges of adjacent parts touch themselves. From this point of view, the study of the assembly geometrical properties becomes a tridimensional problem, whose complexity grows with the number of contacts and shape of the involved features. If parts had nominal shape, then the assembly would be univocally determined and solved by using any CAD tool. Real assembly conditions are far from the ideal ones, because real geometries exhibit a certain dispersion due to the manufacturing processes. As a consequence, the assembly output is no longer univocally determinable and functioning measurements become dispersed as well. The contactor designer controls and limits the variability of the functional measurements (trying to keep them between the acceptance limits) by assigning proper dimensional and geometrical tolerances to the components. The investigation of how tolerances affect the dispersion of the functioning measurements is carried out through a statistical approach.
The contactor that has been analyzed in the consulting service is composed by existing parts (i.e. taken from other production lines) and specifically designed new parts. EnginSoft contribution has made possible to predict both mean values and dispersions of the 5 functioning dimensions selected by the customer and shown in Figure 1. At the same time, an extensive sensitivity analysis has made possible to identify the factors influencing these dimensions, which are the key information to assess corrective strategies in case of unsatisfying distribution of the outputs.

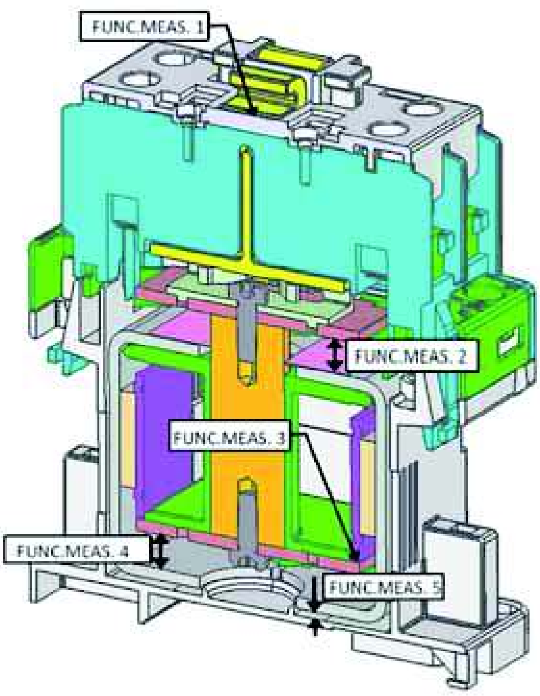


Fig. 1 - Contactor section highlighting the 5 functioning measurements

The service was completed through different tasks. First, the 3D CAD model was analyzed in detail to understand how the components interact and to select the surfaces involved in the contacts. Then, the dimensional chains were written accordingly. Each dimensional chain provides a vectorial representation of the geometrical relationships between component dimensions and functional measurements. For the analyzed device, it was found that 35 dimensions (among hundreds available) were affecting the functional measurements. As expected, the 5 dimensional chains resulted to be interdependent, since some dimensions were simultaneously included in more than one relationship. At the end of the problem definition, a virtual model of the contactor was developed, and the values of the 5 functioning measurements were calculated.

A model used to investigate GD&T problems needs to faithfully reproduce geometrical interactions between parts. In order to meet such requirement, the virtual assembly is performed by putting into contact both surfaces and edges, instead of aligning planes and axes as we normally do in a CAD environment. The hardest phase of such work, which is also the deeper added value of this service, is really the mathematical description of the tridimensional interactions between component features.

The model is finally parameterized, so that it includes the variability (in terms of position and size) of all geometrical details involved in the contact definition. Virtual measurements can be taken easily, in accordance to the model purposes. It is not difficult to see that a model with the mentioned characteristics, virtually reproduces any possible configuration of the multi-part assembly. From a different perspective, we could look at the model as to a numerical representation of the dimensional chains previously identified: it correlates the outputs (i.e. the functioning measurements), to the inputs (i.e. the component dimensions).

The statistical investigation of the GD&T problem was carried out by assigning a normal distribution to each dimension of the components. This was an arbitrary choice, since we did not have information about. Obviously, we could have assigned any kind of distribution to each dimension. Mean values were picked in the middle of the corresponding tolerance ranges, while standard deviations were assumed as equal to 1/6 of the widths. These assumptions relate to the quality of the manufacturing processes we consider. By filling the tolerance range with 6 standard deviations, we implicitly assume that just 1 component out of every 370 has the considered dimension out of its tolerance. We investigated how tolerance effects propagate to the functioning dimensions, by generating a huge number of device configurations in a limited time. Distributions of the 5 outputs were then compared with the given acceptance limits, in order to identify the percentages of devices fulfilling the requirements.

Main results are collected in Figure 2, the distributions of the 5 functioning measurements are compared to the corresponding requirements. All distributions are still of normal type, with symmetric shape. Plots highlight that significant fractions of the entire production are not meeting the operational requirements.

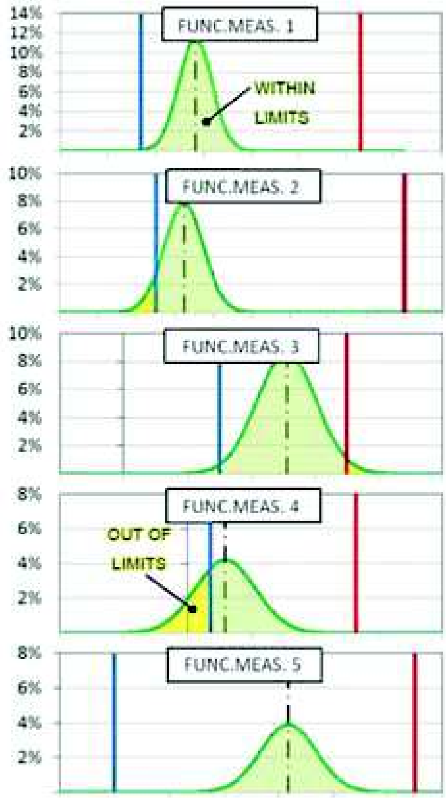


Fig. 2 - Distributions of functioning measurements in the virtual production

The probability for a contactor to not be accepted after assembly is about 37%, mainly because the measurement n. 4 goes out of its acceptance limits. Plots of Figure 2 shows that non conformities can be caused by both an excessive width of the distribution (FUNC.MEAS.3) or a misalignement of the mean value with the acceptance range (FUNC.MEAS.2 and FUNC.MEAS.4).

The statistical sensitivity analysis carried out on the population has made possible to select the dimensions (among the 35 involved) with the highest influence on the 5 outputs. Thus, appropriate adjustments were assessed to reduce the risk of non-conformity. In particular, the mean value of FUNC.MEAS.4 was moved to right (almost making null the area lying out of the acceptance bounds) by adjusting the nominal value of 2 component dimensions. This result really highlights the power of the GD&T analysis: an assembly issue is fixed with no need to narrow tolerance ranges. In other words, the reduction of rejected devices is obtained without increasing manufacturing costs. In this example, the collaboration between Lovato Electric and EnginSoft has returned valuable benefits. EnginSoft has simulated the assembly process through advanced numerical tools, providing crucial information about the relationships between component dimensions and final contactor performances. As issues were identified, proper corrections were planned and verified immediately. This has allowed Lovato Electric to shorten the physical prototyping phase, which turned into an effective reduction of overall production costs.

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