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The new 5 MN hexapod-shaped multicomponent build-up system project

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I.N.RI.M. TECHNICAL REPORT

Abstract

The new 5 MN Hexapod-Shaped Multicomponent Build-Up System (HSM-BUS) represents a significant progress in the field of reference transducers in the high force range. As any build-up system, the presented HSM-BUS can lead not only to measure forces 5 times higher than the capacity of a each single Uniaxial Force Transducer (UFT), but gives also information about the other components of the force vector and of the moment vector.

The goal of the project is mainly to enhance the internal traceability of INRIM force laboratory up to 5 MN, using the HSM-BUS as reference force transducer up the range of 5 MN. Additionally, since this type of BUS is a multicomponent, it would also be used to minimize the spurious component of the force applied by the Standard Force Machine during the calibration of uniaxial force transducers.

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Introduction

The need to have traceable force calibration machines with high capacity, leads to the realization of the Build-Up System (BUS). Such systems are composed by several Uniaxial Force Transducers (UFTs). Generally, a BUS is composed by three UFTs in the same direction, therefore allowing the measurement of a force that is three times the capacity of the single UFT. If it is required to reach higher loads starting from the same UFT capacity, to maintain isostatic condition, it is necessary to create a more complex structure adding additional UFTs in order to increase the total capacity. Another possibility is to use a hexapod structure that use six UFTs, reaching five times the capacity of the system (considering the mounting angles), as it was already developed at INRiM. This structure has also the advantage to allow the measurements of all the six components (Multicomponent Force Transducer, MFT), i.e. not only the principal axial force (*Fz*), but also all force and moment vectors (transversal, *Fx* and *Fy*), and three moment components, (tilting, *Mx* and *My*, and torsion, *Mz*).
The calibration of such type of multicomponent force transducer regards only the calibration of the signal outputs coming from each UFT and the calibration of the geometry of the system.

1 HSM-BUS Design

The hexapod structure use six Uniaxial Force Transducers (UFTs) in order to multiply five times the capacity of the system (considering the mounting angles). This structure has also the advantage to be a Multi-component Force Transducer (HSM-BUS), i.e. it can measure not only the principal axial force (Fz), but also all force vectors and moment ones. The additional information on spurious component can be used to get a better accuracy on the Fz measurements.

1.1 System Geometry

An hexapod-shaped structure is considered a structure having six foots; the ideal structure consists in three pair of each, each one of them create a triangle. The system geometry of the new 5 MN HSM-BUS can be briefly outlined with the views of the XY-plane and of XZ-plane. In the first view (left of Figure 1) we can see the distribution of the UFTs (numbered from 1 to 6) on the plates, the radius r and the angle γ (remembering that angle δ is complementary to it). In the second view (right part of Figure 1), it is clear the inclination of every UFTs with the horizontal, and are shown the two functional angles α and β.

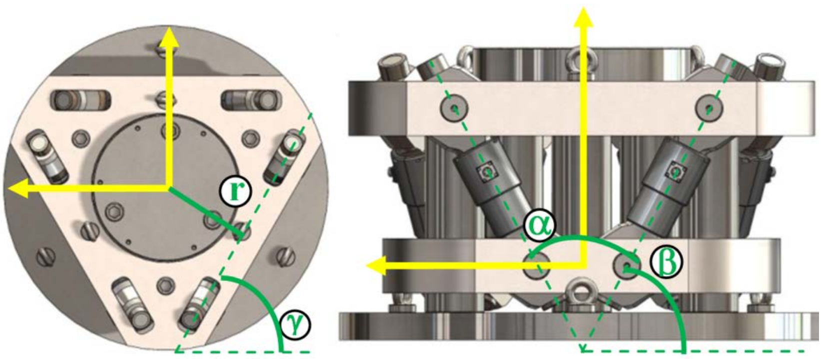

Figure 1: The geometry of HSM-BUS

As it can be seen in Fig. 3, due to dimensional limits, it was not possible to connect two UFTs into the same point; so, instead of a triangle, each pair of UFTs create a trapezoid.

1.2 HSM-BUS Design

The 5 MN hexapod-shaped HSM-BUS is designed to work with a nominal force value of 5 MN, using 6 UFTs with maximum load of 1 MN, in order to be calibrated using the 1 MN Deadweight Standard Force Machine at INRiM.

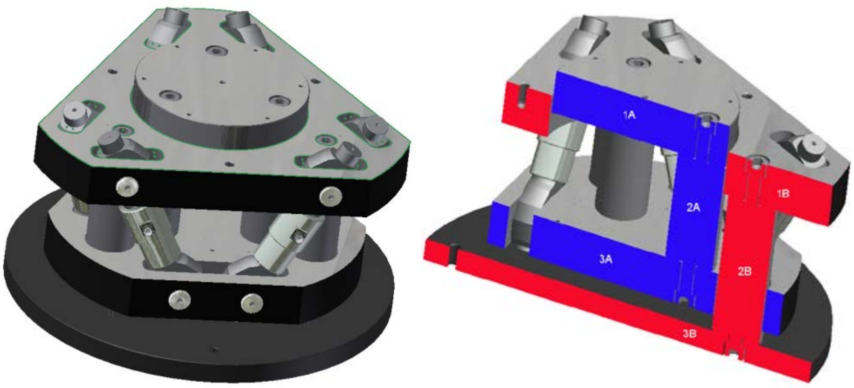

Figure 2: ***The 5 MN hexapod-shaped MFT***

Since the UFTs have to work in traction, and not in compression as the HS-BU, it was necessary to create an inversion frame, in order to put in traction the UFTs. The load, applied on the upper loading pad (1A), is transferred by three columns (2A) to the lower plate (3A), where are fixed the lower clamping heads of the UFTs. The upper clamping heads of the UFTs are instead fixed to the upper plate (1B) which, through three columns (2B), is supported by the base (3B).

1.3 Uniaxial Force Transducers

A HSM-BUS, as every BUS, is composed by several UFTs [1,6]; in a HSM-BUS with hexapod geometry are used six UFTs [7,8], disposed two by two, to recreate an hexapod structure, realizing a pseudo-isostatic structure.

Another peculiarity of the hexapod-shape HSM-BUS, is that its UFTs work in traction, and not in compression as in a generic BUS. A further difference is the inclination of the UFTs respect the horizontal plan, which leads to the necessity re-orient the single UFT continually in order to avoid spurious components and flex-traction effects. This re-orientation movement can be obtained using a couple of elastic hinges at both ends of every UFTs, but, due to dimensional limitations, the using of elastic hinges is not possible, and it was used spherical joints.

Figure 3: ***a) uniaxial force transducer (UFT), b) spherical joint***

The force will be carried out to every single UFT through plugs passing among the plate and the spherical joints.

2 Technical drawings

At the end of this presentation, we have shown the most relevant technical drawings, i.e. the two plates and the UFT. A pair of UFTs create an ideal trapezoid, characterized by the following geometrical characteristics:

Side	Symbol	Value / m
upper base	*s*	4,6706 x10^{-1}
lower base	*t*	1,6600 x10^{-1}
diagonal	*d*	3,2600 x10^{-1}

Table 1: sides of the ideal trapezoid

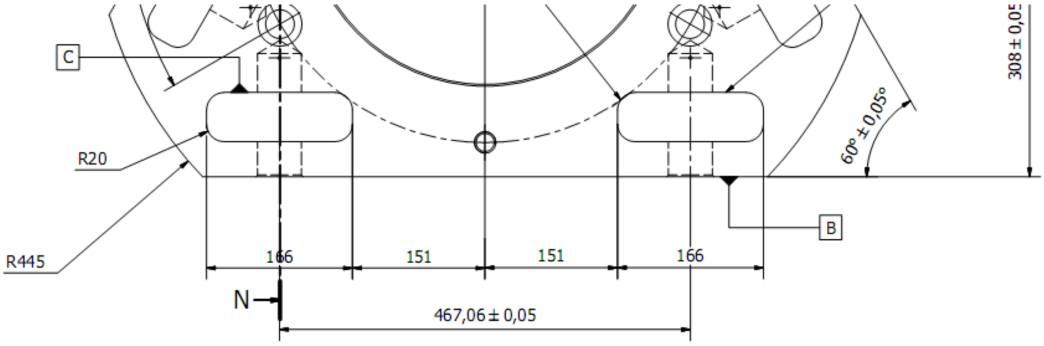

Figure 4: upper plate front detail

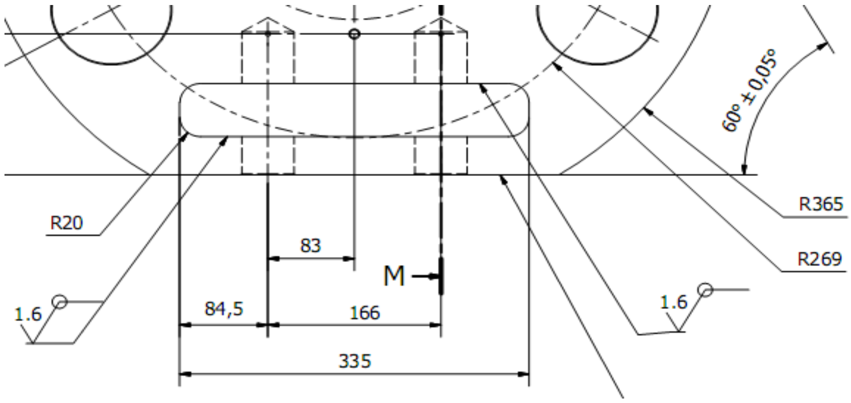

Figure 5: lower plate front detail

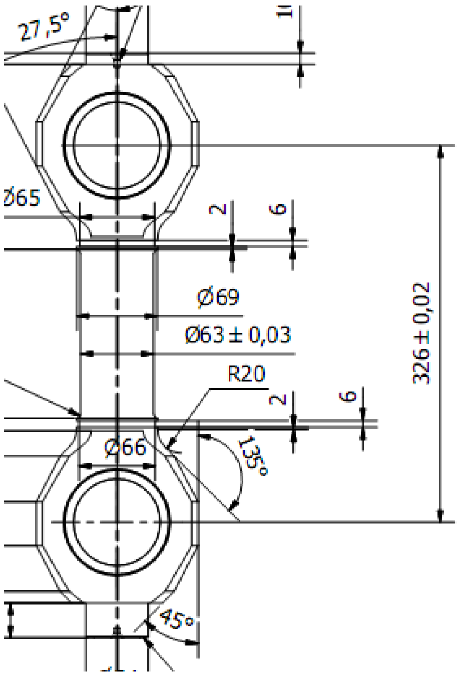

Figure 6: UFT dimension lines

From the values shown in Table 1, it is possible to evaluate the functional angles α and β seen in Fig. 3, using the following equations:

$$\alpha = 2 \cdot \sin^{-1}\left(\frac{s-t}{2 \cdot d}\right)$$
$$\beta = \cos^{-1}\left(\frac{s-t}{2 \cdot d}\right)$$

1

and the results are summarized in Table 2

Angles	Radiant	Degrees
α	9,60 x10^{-1}	55°
β	1,09 x10^{0}	62,5°

Table 2: values of the functional angles

To complete the geometric characteristics of the HSM-BUS, remain the two complementary angles γ and δ, which values are shown below:

Angles	Radiant	Degrees
γ	1,05 x10^{0}	60°
δ	5,23 x10^{-1}	30°

Table 3: values of the complementary angles

3 Force measurements

The main characteristic of a HSM-BUS is that the values of the force and moment vectors are given by the combination of the signal coming from the single UFTs. Every component of the two vectors can be evaluate using the following equations:

$$F_X = [(F_6 - F_5) - (F_2 - F_1)] \cos\beta \cos\delta$$
$$F_y = -(F_4 - F_3)\cos\beta - (F_5 - F_6)\cos\gamma - (F_1 - F_2)\cos\beta\cos\gamma$$
$$F_z = (F_1 + F_2 + F_3 + F_4 + F_5 + F_6)\cos\frac{\alpha}{2}$$
$$M_x = [(F_1 + F_2) - (F_5 - F_6)]\cos\frac{\alpha}{2} \cdot 2r\cos\delta$$
$$M_y = -\frac{(F_4 + F_3)\cos\frac{\alpha}{2}}{\frac{1}{r} - (F_1 + F_2 + F_5 + F_6)\cos\frac{\alpha}{2}} r \sin\delta$$
$$M_z = (F_1 - F_2 + F_3 - F_4 + F_5 - F_6) r \cos\beta$$

2

4 *Stresses analysis*

The last part of this panoramic view of the new 5 MN HSM-BUS is pointed on the simulation of loads and the analysis of the stresses, to ensure that the entire project was properly designed. The most important element to analyse is, obviously, the single UFT. In the simulation, the single UFT is oriented in the space as inside the HSM-BUS, and the load was applied during the Z-direction through the lower spine, while the higher ones was used as reference.

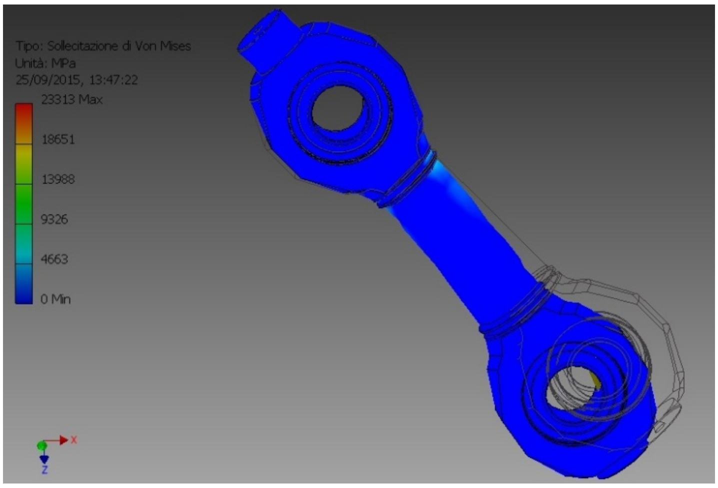

Figure 7: Von Mises stresses of a single UFT

The application of high value of load, in the range of the mega newton, create flex-traction effects that cannot be neglected, and this is the reason of the presence of the spherical joints; if the UFT has the possibility to be re-oriented, it is the possibility to avoid, or least minimize, flex-traction effects.

The presence of flex-traction effects are well underlined in the analysis of the shift in the Z-direction, shown in Figure 8:

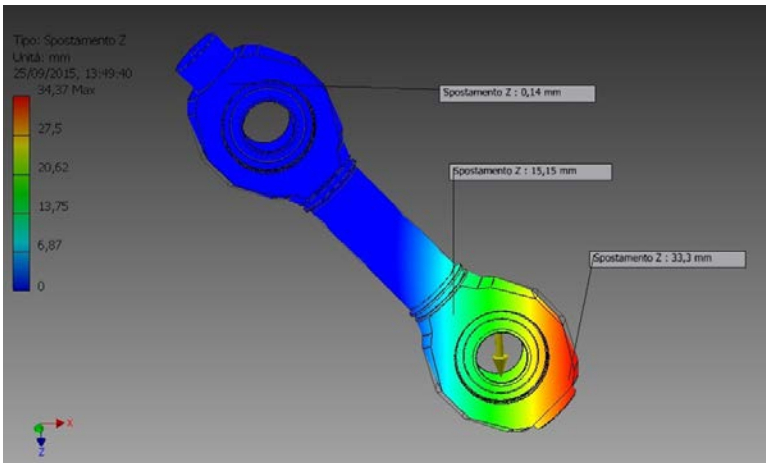

Figure 8: shift of a single UFT on the Z-direction

The re-orientation of the each pairs UFT in the HSM-BUS under loads (due to the use of spherical joints) and the new angles formed between them, are well represented and can be easily obtained by the analysis of the shift in Z-direction:

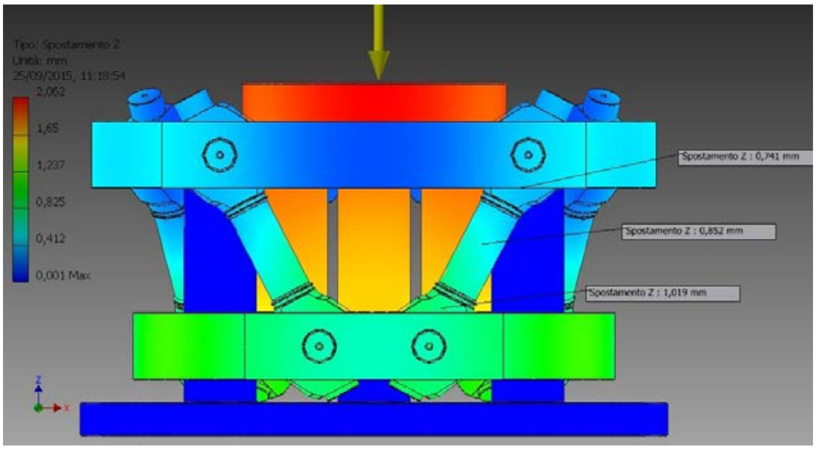

Figure 9: shift of the HSM-BUS on the Z-direction

Other important elements of the HSM-BUS that suffer deformations under loads are the two plates:

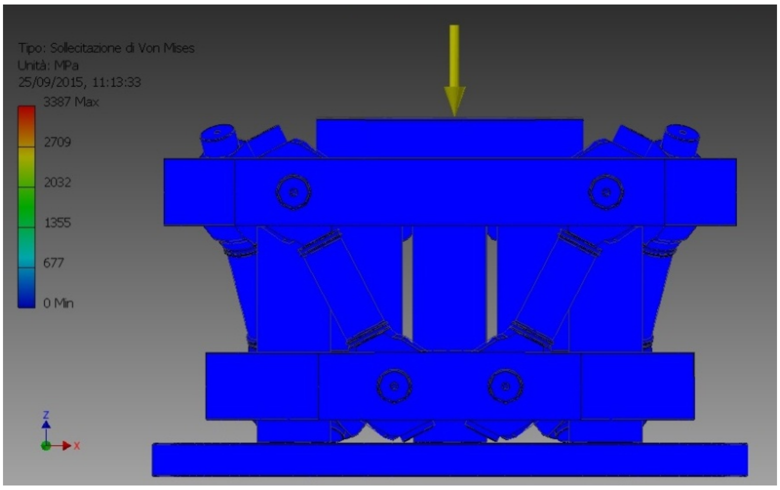

Figure 10: Von Mises stresses of the HSM-BUS

The analysis of the Von Mises stresses, in this case, are not sufficient to underline the deformations, while the shifts on the Z-direction are much more clarifiers:

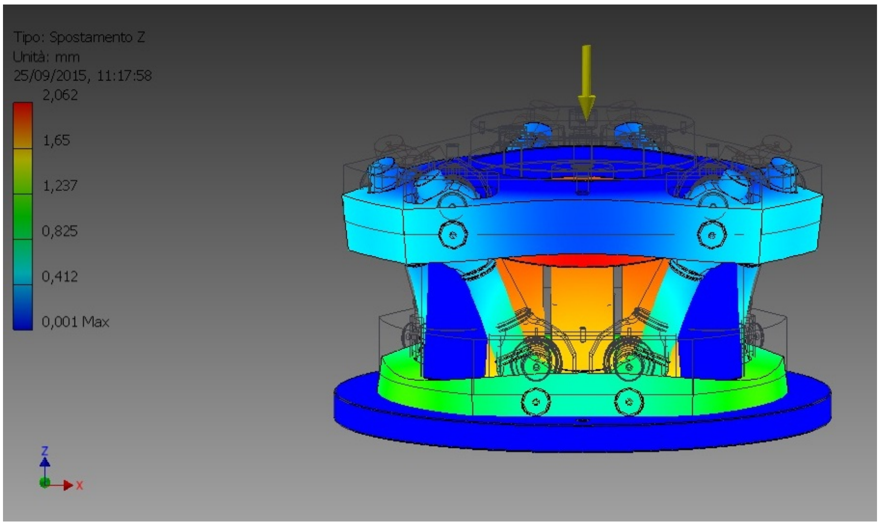

Figure 11: software amplification of the deformation of the HSM-BUS under load

The figure above, obtained with a software effect that amplifies the deformation, can shows easily that both the plates do not go down united, but that these plates have the same behavior of a shelf with the load applied on the side. In the below figure, at the end, are shown the final shifts on the Z-direction of different points to give a numerical information of these deformations.

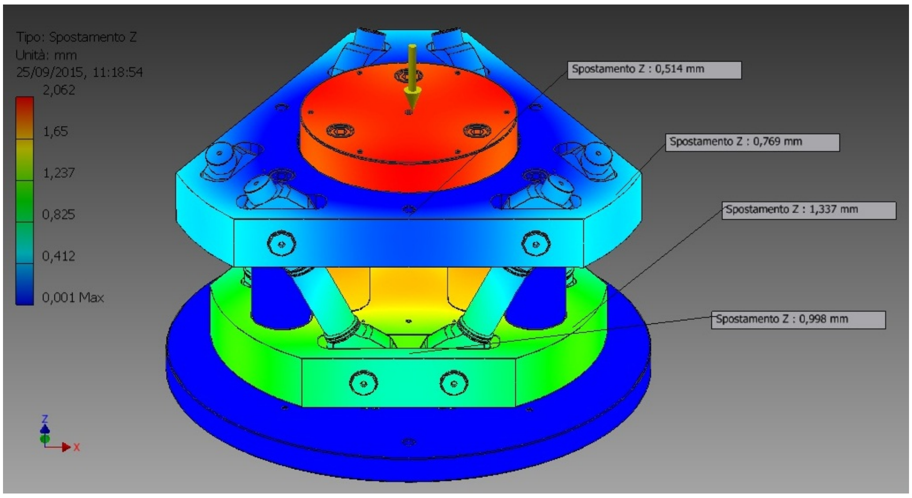

Figure 12: final shifts details on the Z-direction

5 Conclusions

The stresses analysis shows that the new 5 MN Hexapod-Shaped Multicomponent Build-Up System (HSM-BUS) is properly designed and can be used up to 5 MN. At the same, the deformations on the upper and lower plates should be experimentally verified in order to avoid undesired influences on the force measurements.

Appendix A: technical drawings

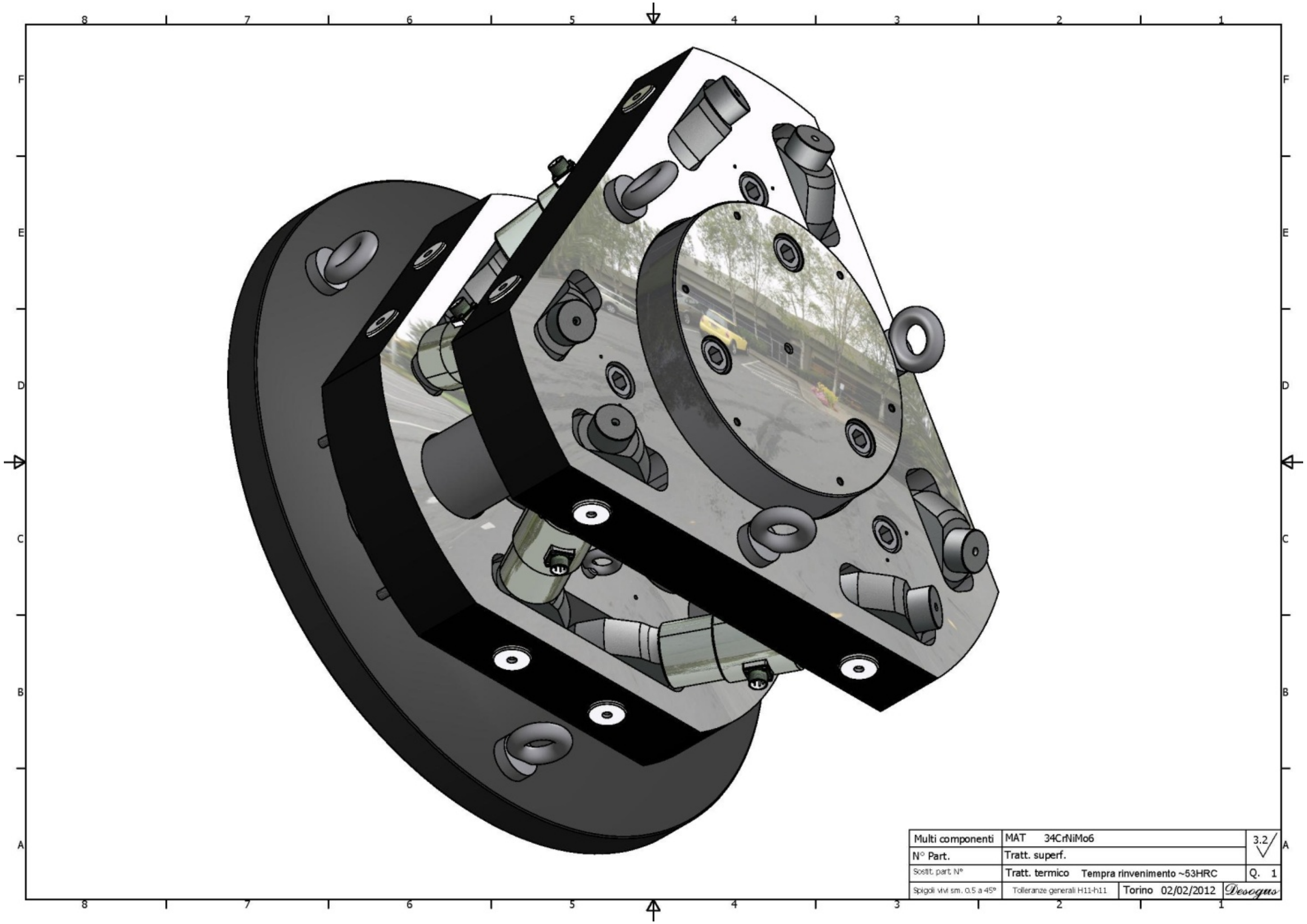

Figure 13: the new 5 MN HSM-BUS

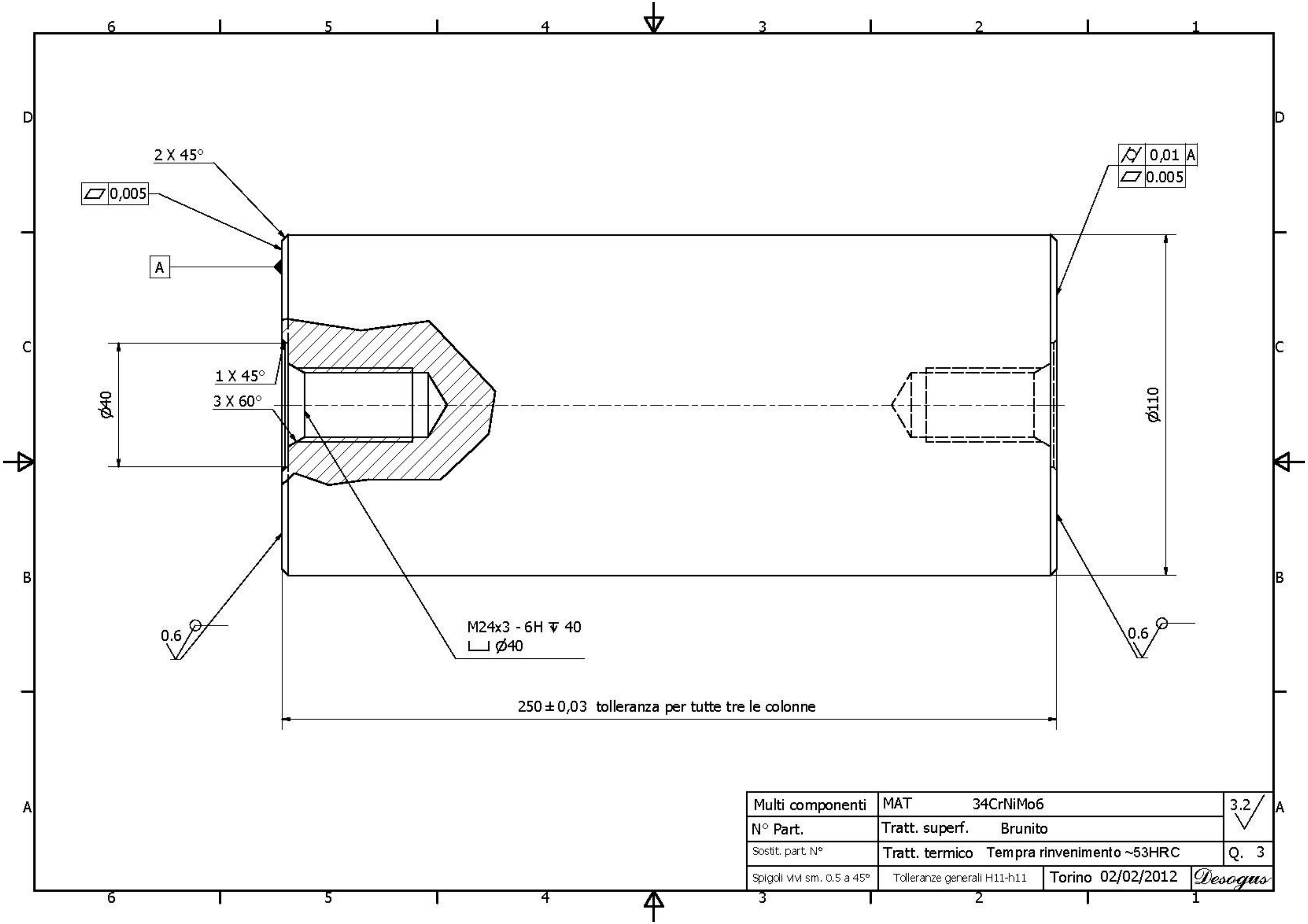

Figure 14: internal column

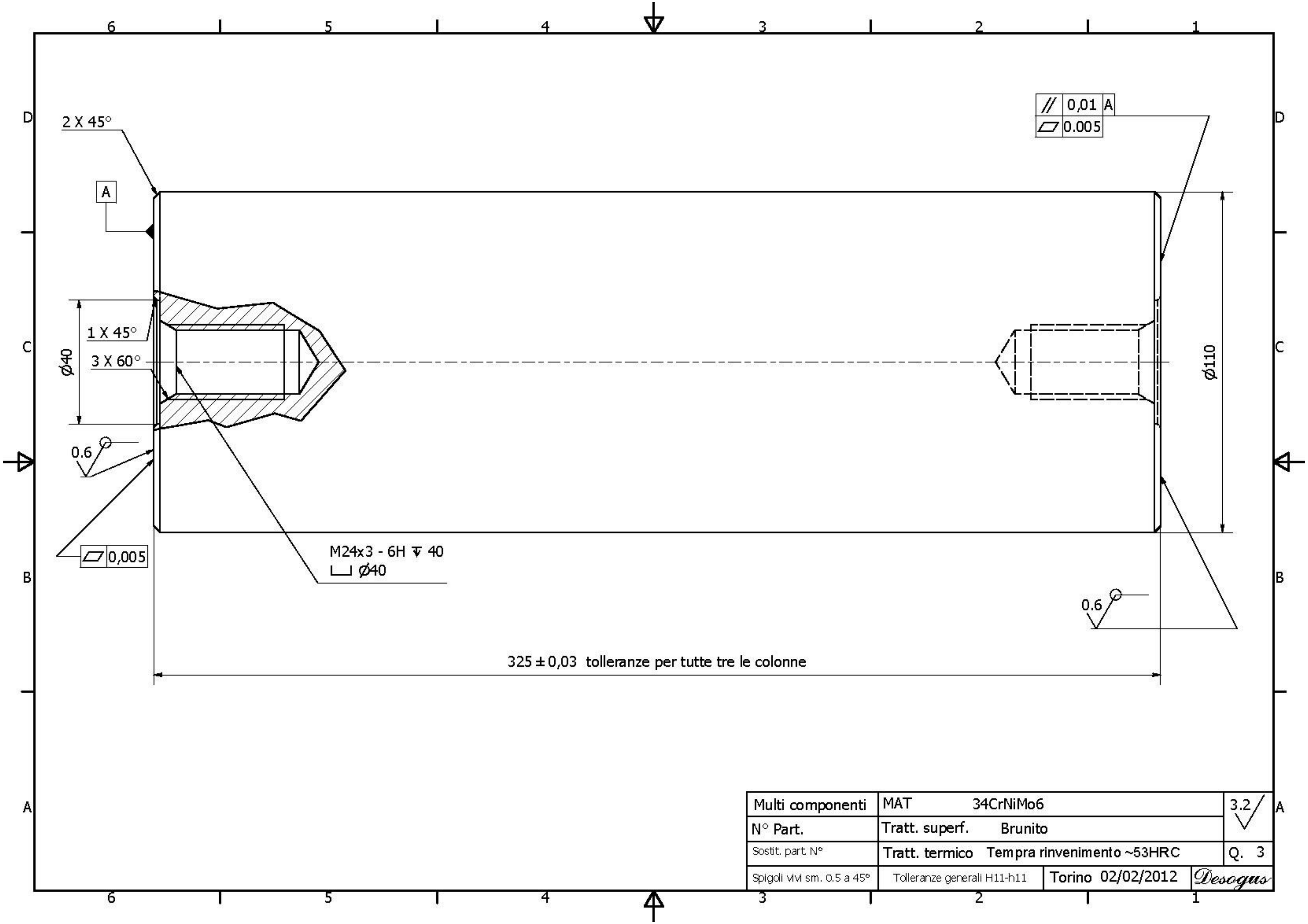

Figure 15: external column

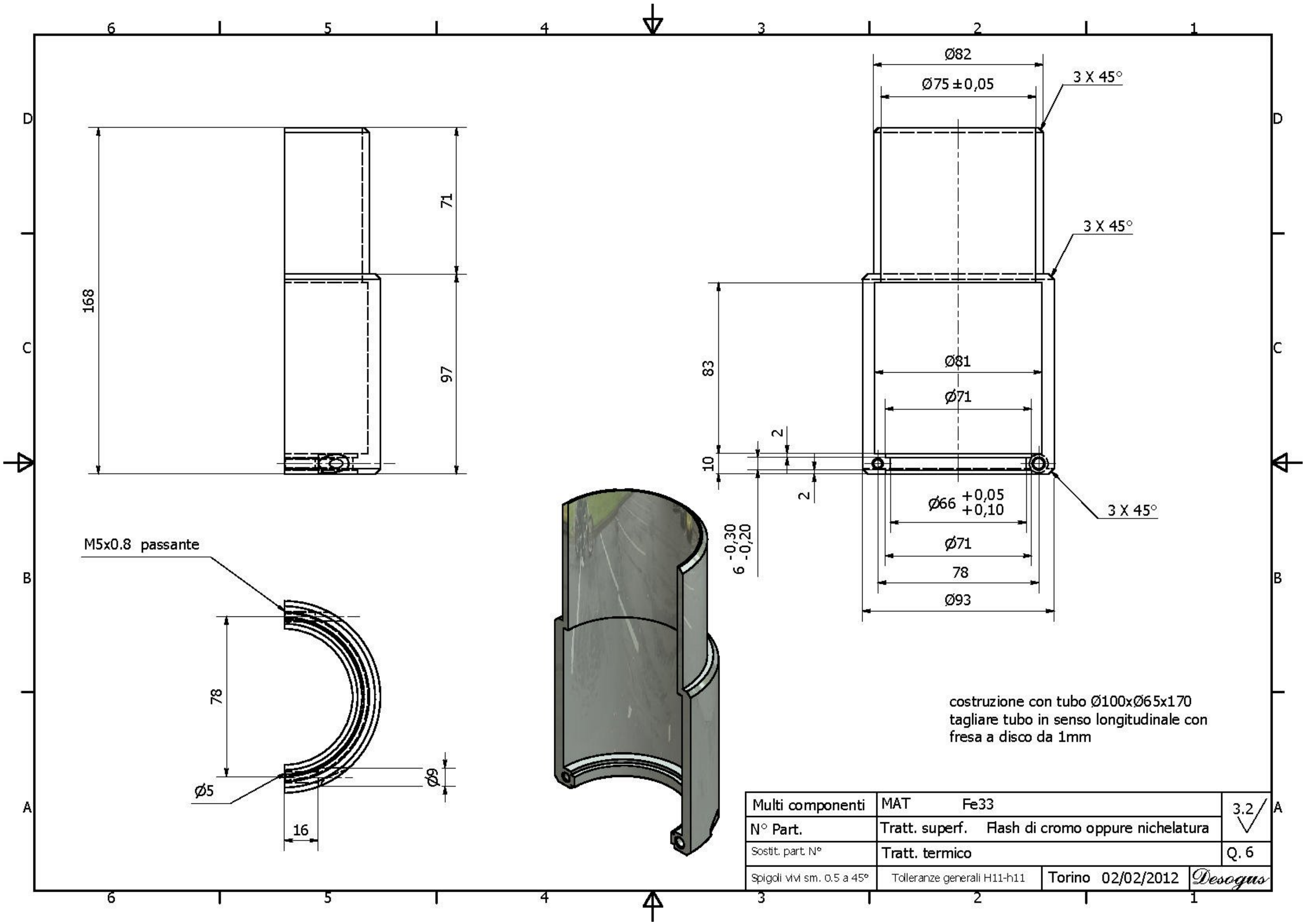

Figure 16: extensometer rear cover

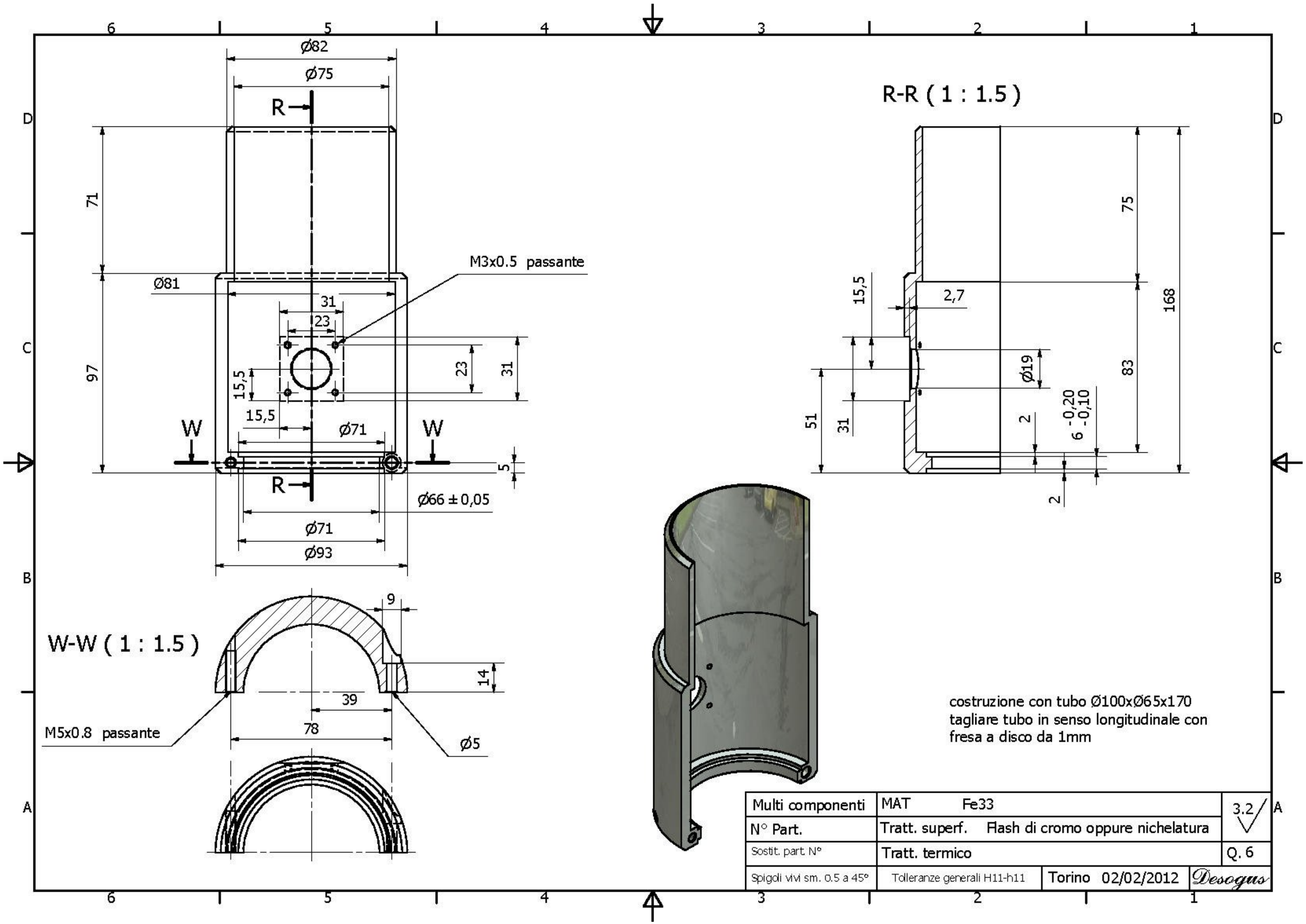

Figura 17: extensometer front cover

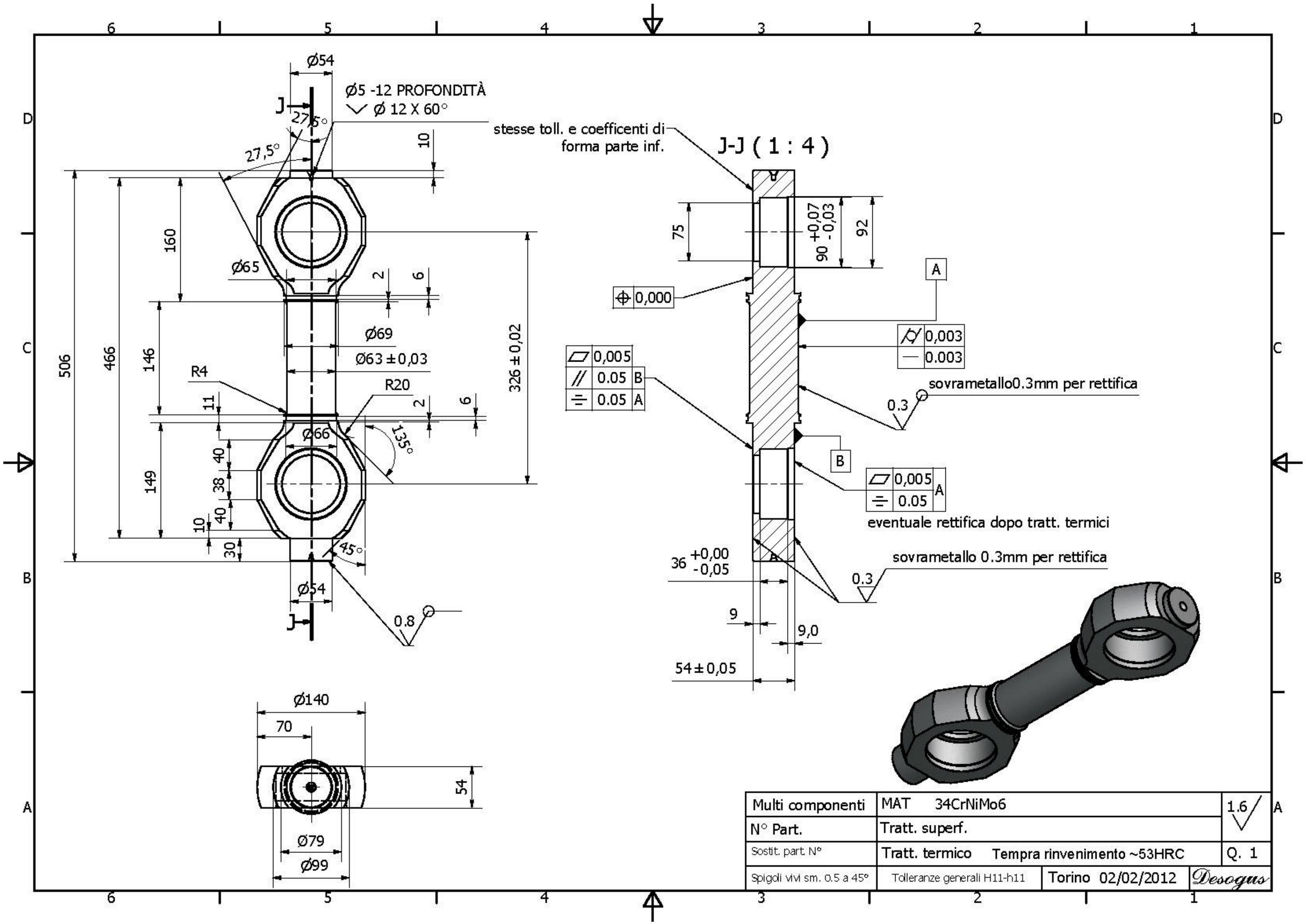

Figure 18: 1MN UFT

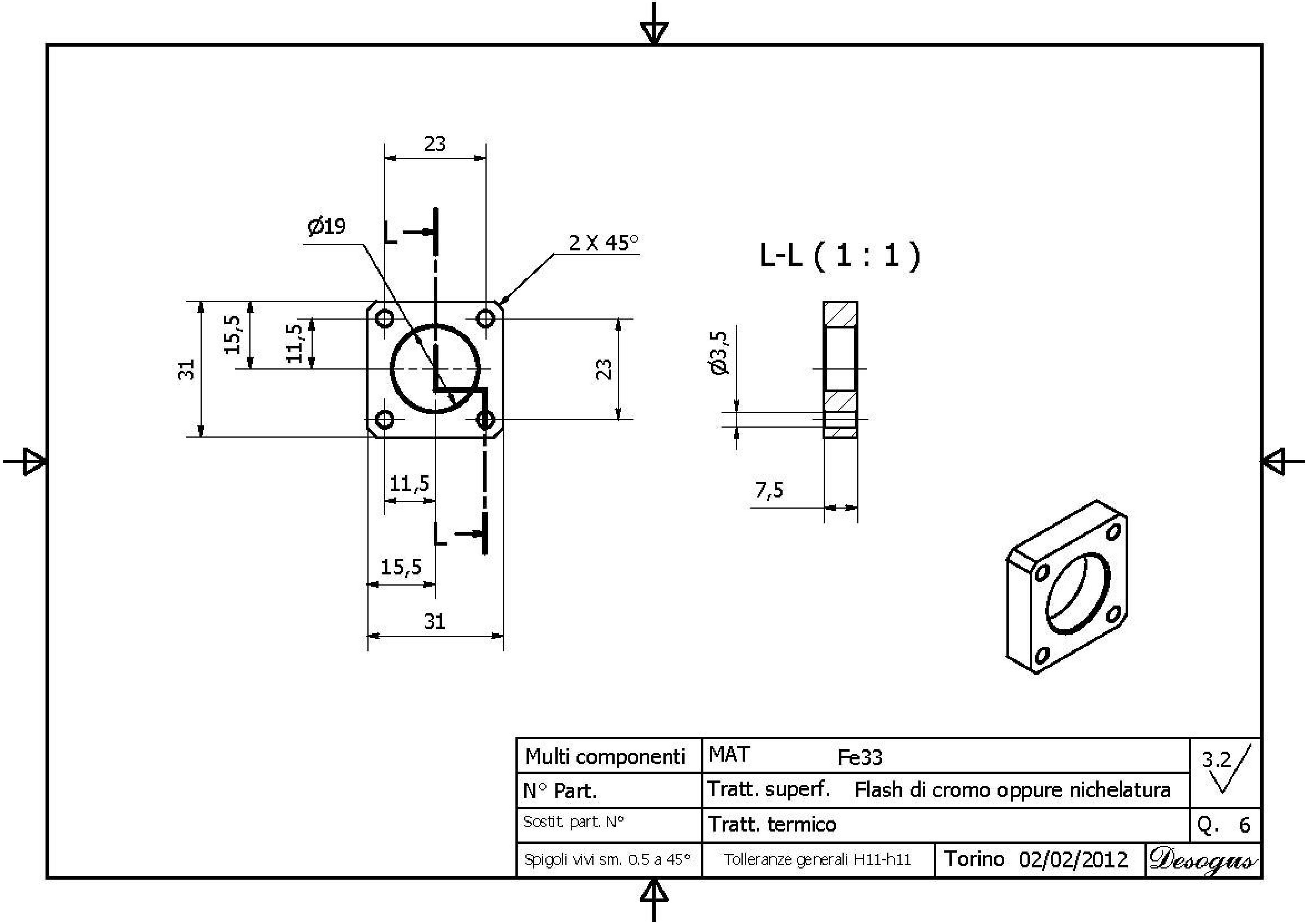

Figure 19: connector spacer

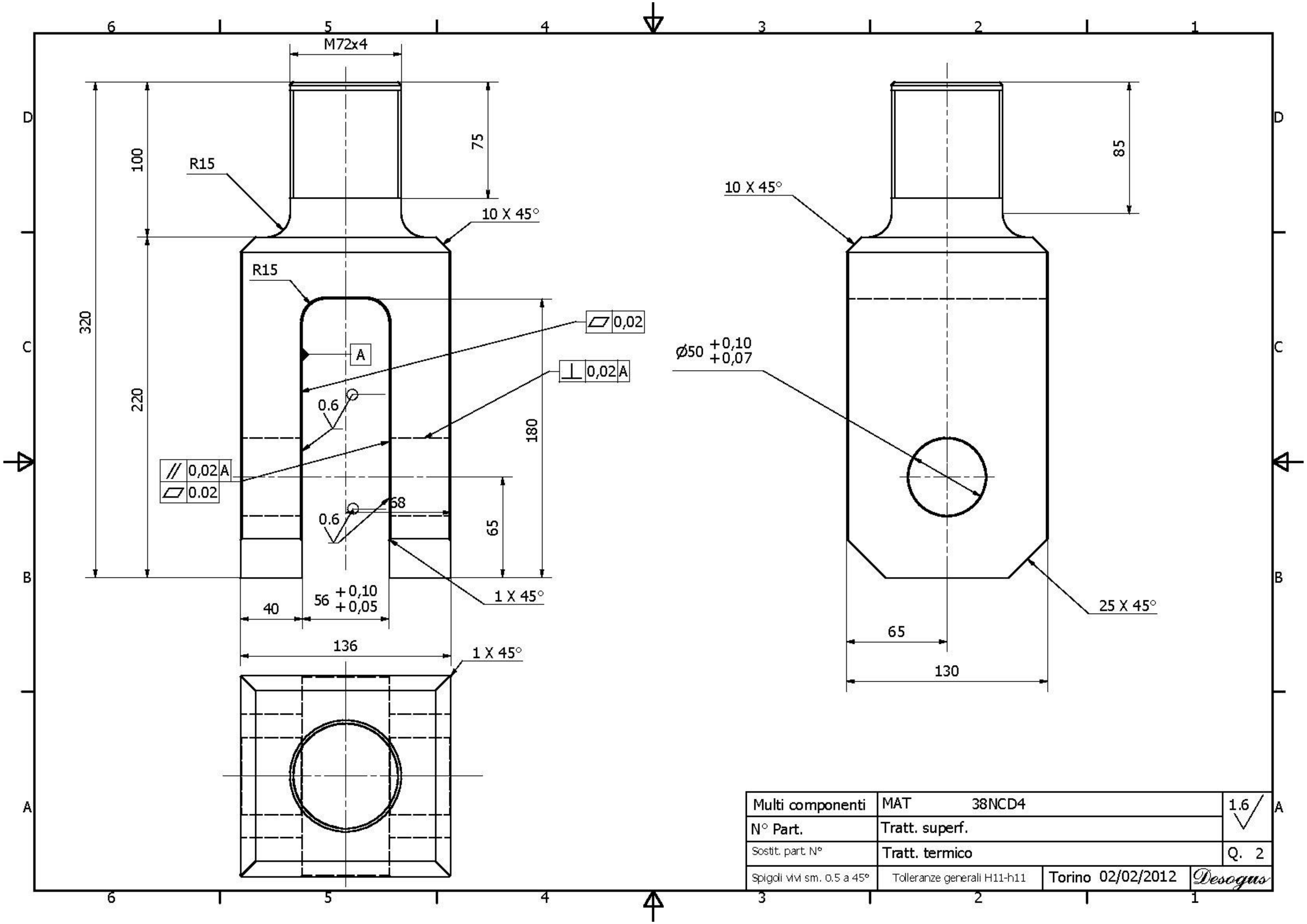

Figure 20: calibration fork

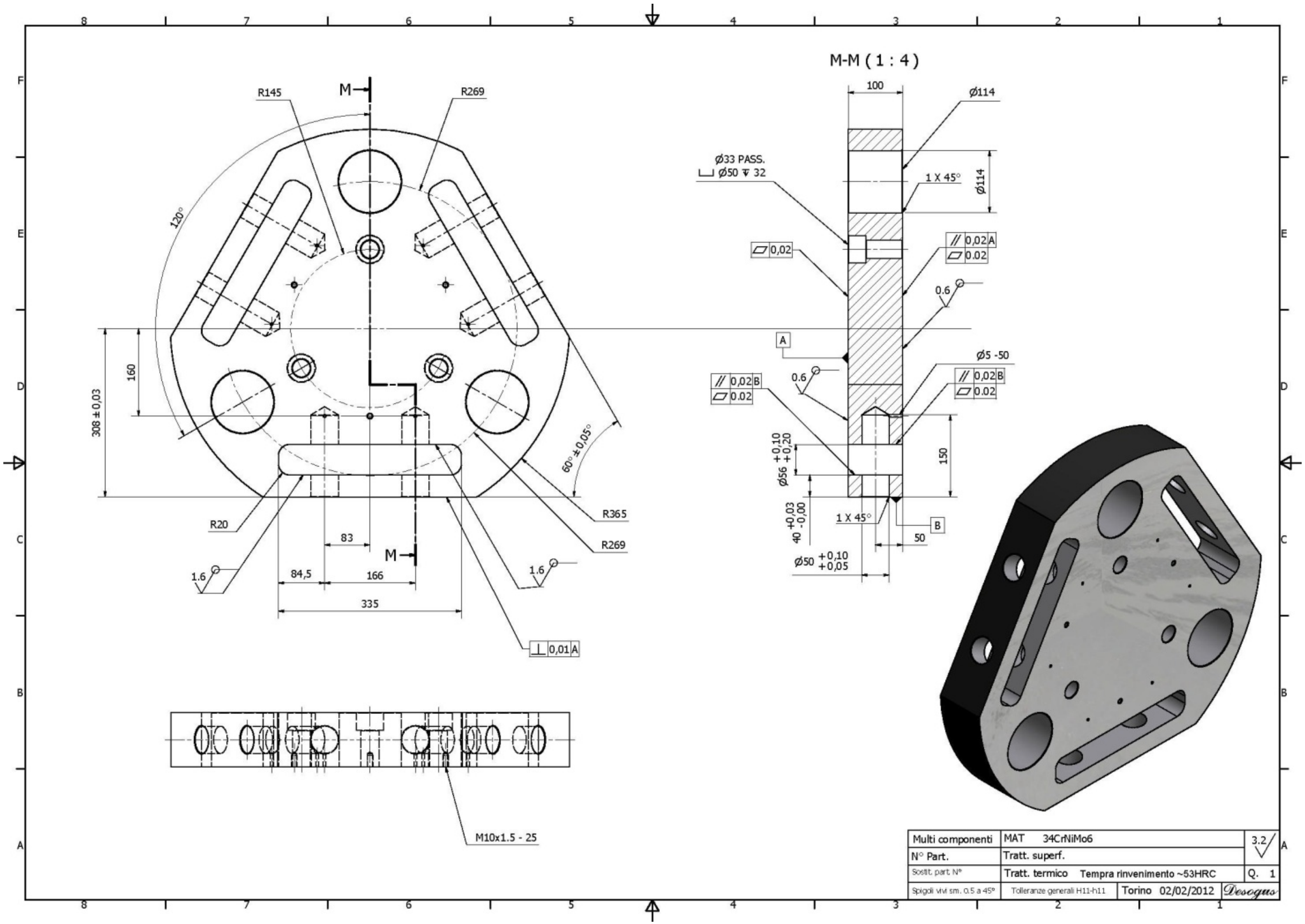

Figure 21: lower plate

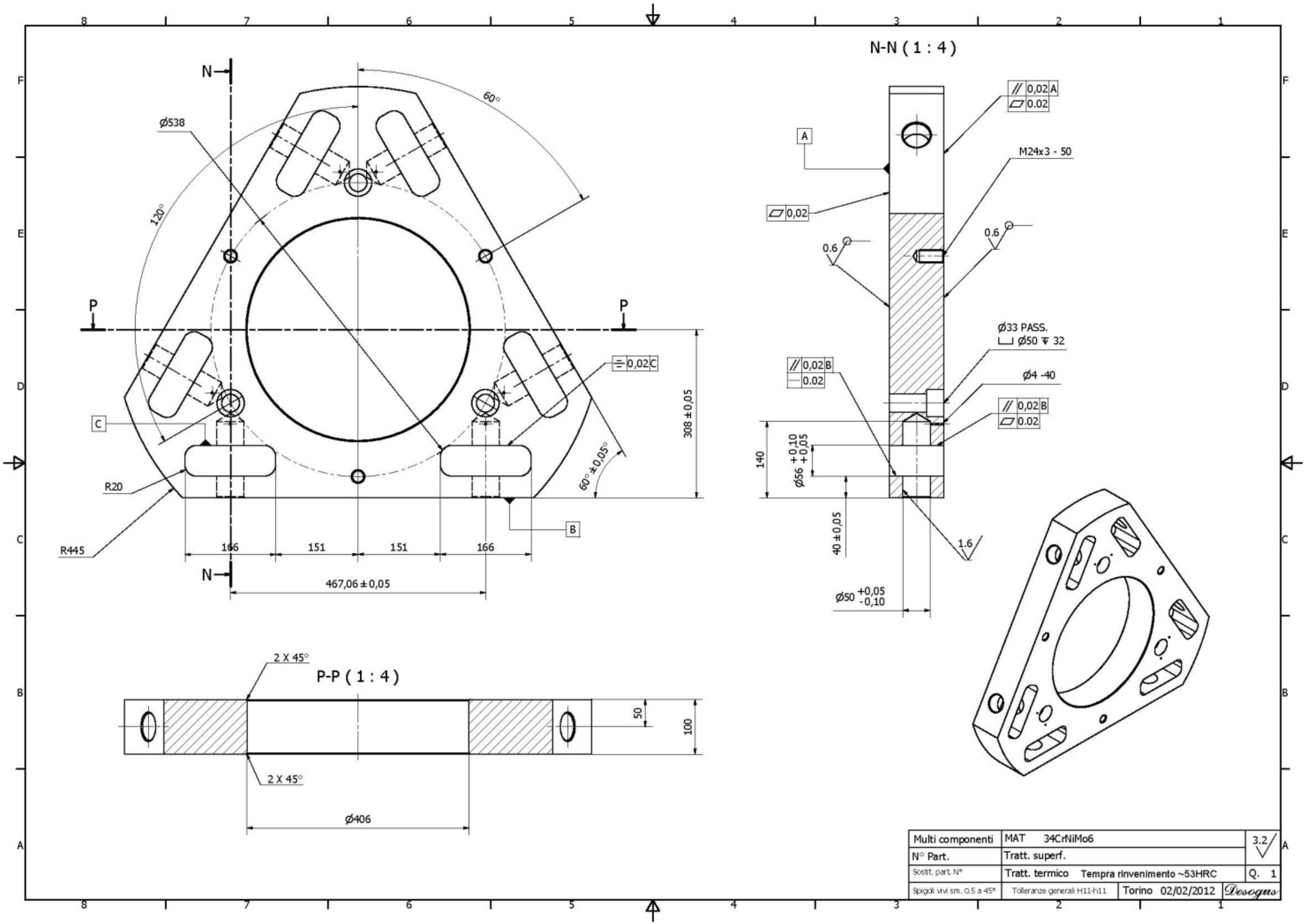

Figure 22: upper plate

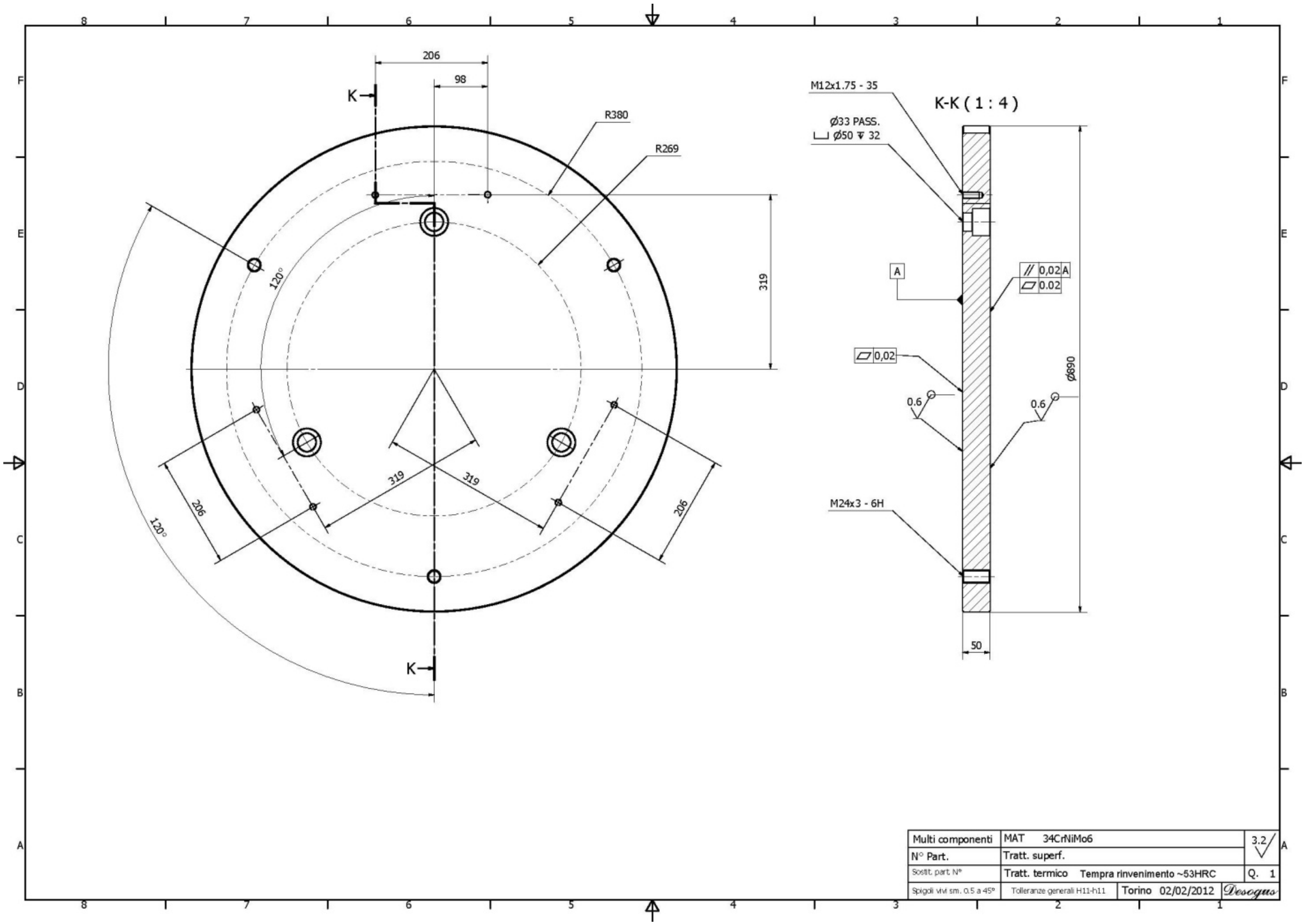

Figure 23: HSM-BUS basement

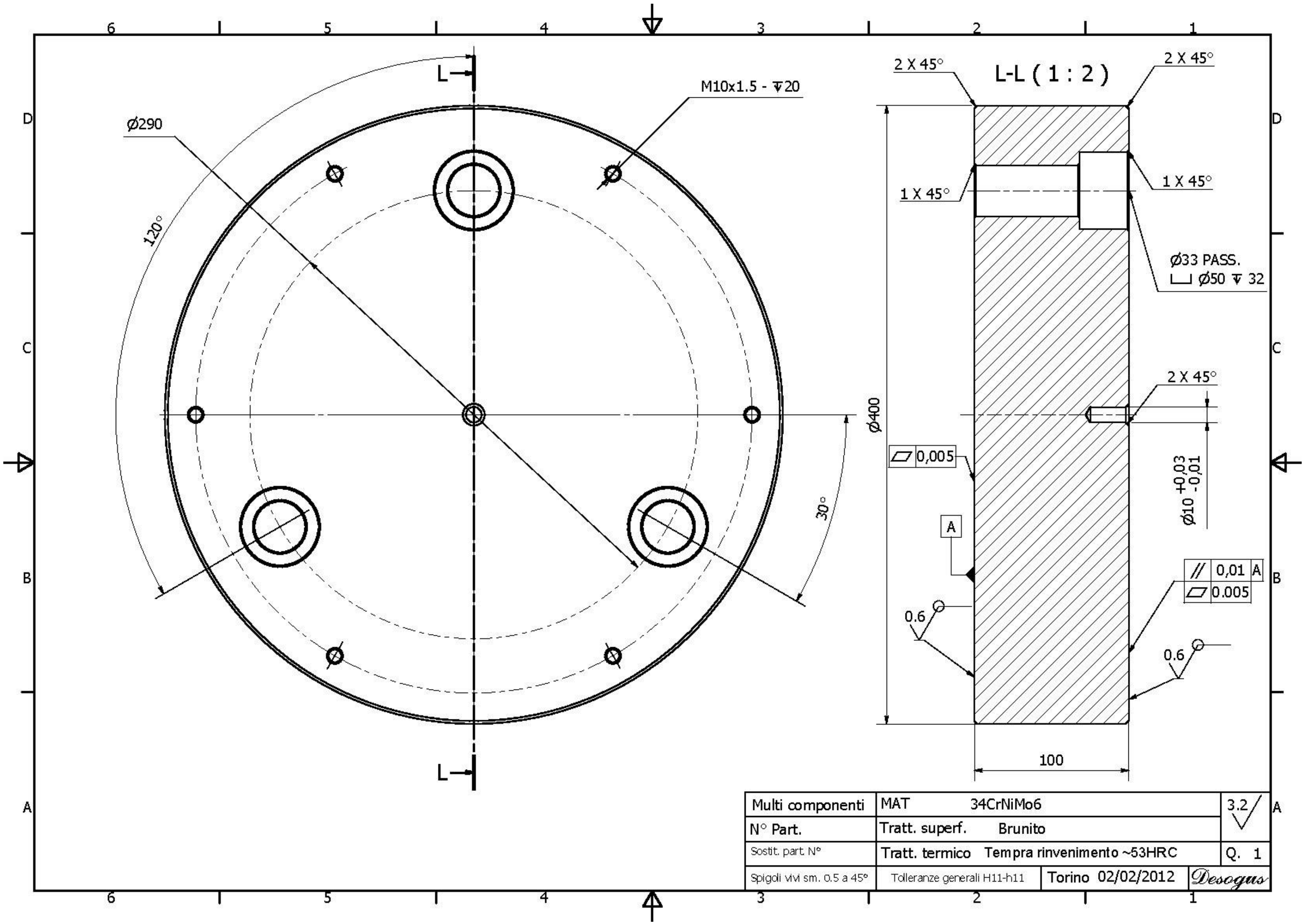

Figure 24: upper clamping head

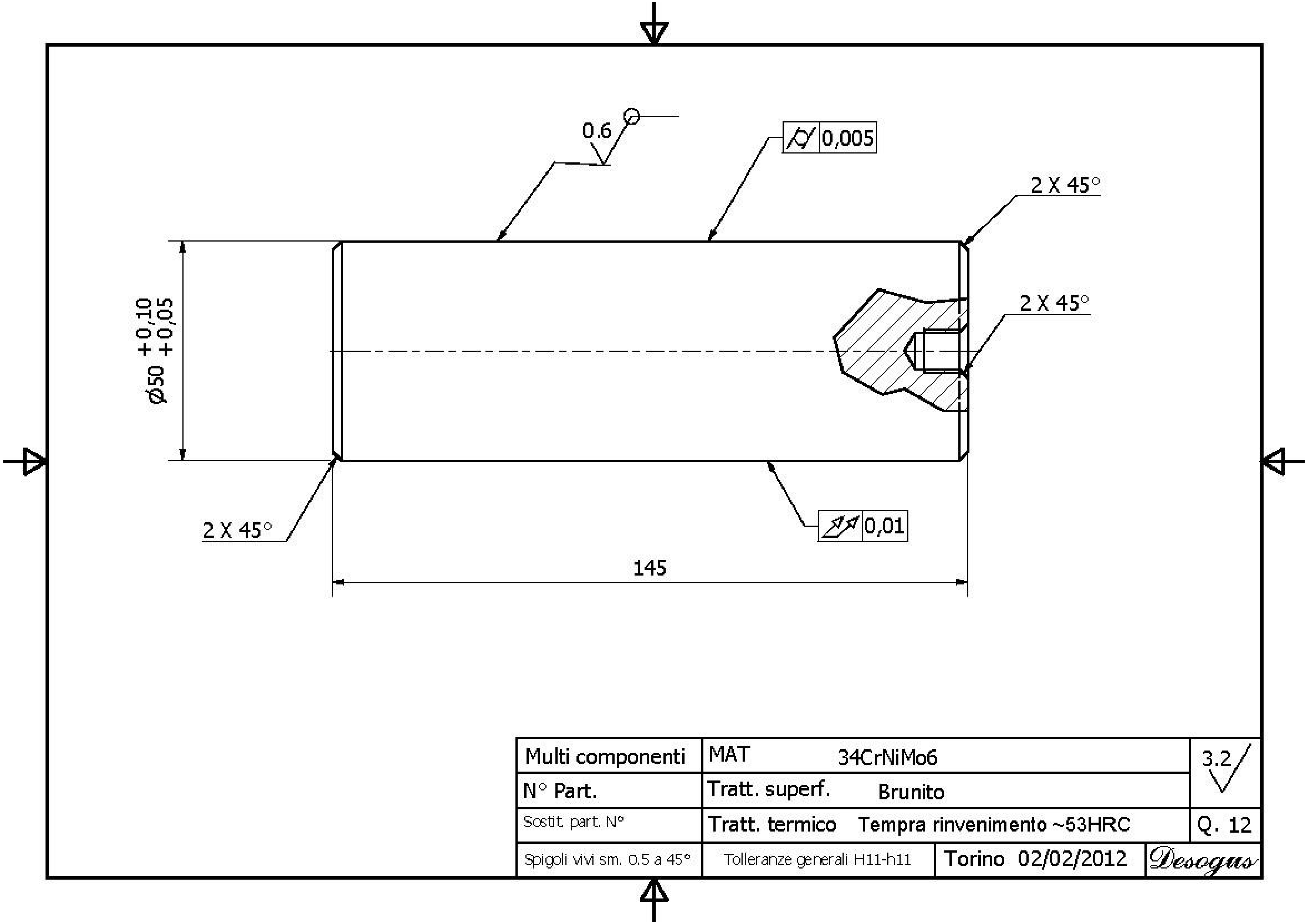

Figure 25: plug

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