

Compact Fixturing Based on Magneto-rheological Fluids for Aeronautic Stringers Milling

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ABSTRACT

The paper explains the compact fixturing based on magneto-rheological (MR) fluids that have been designed and validated for aeronautic stringers milling. The MR fluid based tooling developed is flexible and reconfigurable as it can be adapted to different profile's lengths and sections and it is able to fix compliant workpieces without reference faces as the MR fluid adapts to the outer shape of each profile. The MR fluid based tooling is suitable to hold non-magnetic materials such as aluminum and also materials that do not admit high clamping forces, such as titanium, because they will appear as deformation after machining due to the memory effect of titanium. The MR fluid based tooling has been tested in a machine environment under real machining conditions and promising results have been obtained.

INTRODUCTION

In the components manufacturing sector it is considered by many experts that fixturing is the last obstacle to truly flexible manufacturing operations. In fact, fixturing frequently constitutes a costly and time-consuming

barrier to meet the challenge of shorter runs needed by more demanding consumers. Variety in choice of products is what consumers seek and what manufacturers have to provide.

The workholding systems produced for difficult-to-handle workpieces [1] (such as complex curved surfaces, compliant workpieces – as non-rigid “skin” type - or those whose structure weakens while machining progresses or workpieces without reference faces) which are only required in small batches can account for up to 80 percent of total process costs. In sectors subjected to high cost pressure, such as aeronautical and aerospace industries, there is a distinct need for alternative fixturing devices suitable to hold workpieces of any shape and condition. [2]

Workholding systems based on liquids which are solidified by freezing, for example, have already been tried out [3], [4], [5]. In most liquid-based methods the workpieces are completely or partially immersed in a tank containing a liquid such as water or a special polymer material which is then cooled, solidifying in the process and holding the part to be machined in position. These temperature-induced phase transitions, however,

entail the risk that the part to be machined will itself expand or contract. In extreme cases such changes in dimension can negatively influence the precision and reproducibility of the subsequent machining process. What's more, the phase transitions of the liquid consume a lot of energy and time.

By contrast, magnetorheological fluids [6], [7], [8] which in the liquid state have the consistency of viscous oil, solidify under the influence of a magnetic field within fractions of a second. The MRF also adapts to small geometrical fluctuations and can thus be used to apply uniform holding forces even on workpieces of large surface areas. Slight shape inaccuracies or changes in shape are compensated. As MRFs simultaneously suppress vibrations, such as those that occur in milling operations, they make it possible to process sensitive parts particularly gently and with high precision. [9]

This reflection has lead the authors to develop, manufacture and experimentally validate a compact fixture based on magneto-rheological (MR) fluids capable of locating, clamping and supporting firmly long and compliant workpieces without reference faces. In particular, a MR fluid based tooling has been built and tested for fixing titanium T-shape aeronautic stringers (whose width varies between 74 and 76 mm and whose length varies from 422 to 1400 mm) while some of their faces and contours are being milled.

MAIN SECTION

REQUERIMENTS FOR MRF-BASED FIXTURING SYSTEMS

The workpiece to be fixed is a secondary structural element integrated in the belly fairing structure of an airplane which functionality is to support the exterior and interior aerodynamic panels. Such part consists in a titanium T-shape profile with curvature. Many different profiles are manufactured by ACITURRI AERONAUTICA with these general parameters being main differences their longitude which ranges from ~414 mm to ~2.875 mm, the curvature depending on the position in the complete structure and the inclination degree of the middle wall of the profile. The manufacturing process developed by ACITURRI AERONAUTICA to obtain such pieces consists in conventional machining of an extruded part with similar T-shape and approximately 4 mm extra of material referred to the final required dimensions.



Figure 1. Picture of the titanium T-shape aeronautic stringers.

Nowadays, the part is machined in 4 stages and 4 tooling fixtures are needed. The part is flat in the first three stages and before locating it in the fourth fixture, the part is curved.

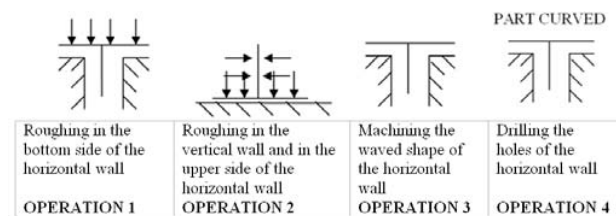


Figure 2. Complete conventional process of manufacturing the titanium T-shape aeronautic stringers

The most difficult thing in this system is how to hold the part because the profile must be really well placed on the surface but it will not be completely flat until the first roughing is done. The extruded profiles have a near net-shape (non perfect form) and to assure the tolerances of the finished parts, considering the memory effect of titanium, the workpiece's geometry and the cutting forces it is necessary to moor the part in a free state, without introducing any forces into the part. Any forces introduced during the mooring will appear after machining, as deformation. A second *disadvantage* is the need of using 4 tooling fixtures for its manufacturing. And a third disadvantage is that the time for fastening the part goes from 25% up to 50% of the total manufacturing time depending on the profile's length.

Taking into account the characteristics of the workpiece, the **main requirements of the MR fluid-based tooling prototype** for the T-shape stringers are the following:

- Support the machining forces
- Ensure the tolerances of the design
- Reduce the non-productive manufacturing times by about 30-40%
- Reduction of the actual number (4) of tooling fixtures
- Reduction of the time for loading and unloading the workpiece by 50%
- Be flexible and reconfigurable to be easily adapted to different profile's lengths and sections (sections'

width range goes between 74 and 76 mm; profiles' length range goes between 422 and 1400 mm.

CONCEPTUAL DESING OF THE MRF BASED TOOLING

The most suitable tooling to be designed with MR fluids is the tooling for the operation 2 (see Figure 2) that is the roughing of the vertical wall and upper side of the horizontal wall. The new tooling will change the process allowing performing this operation first to be followed by operations 1 and 3 that could be done in actually available tooling number 3 with small modifications. Tooling number 1 will not be more needed.

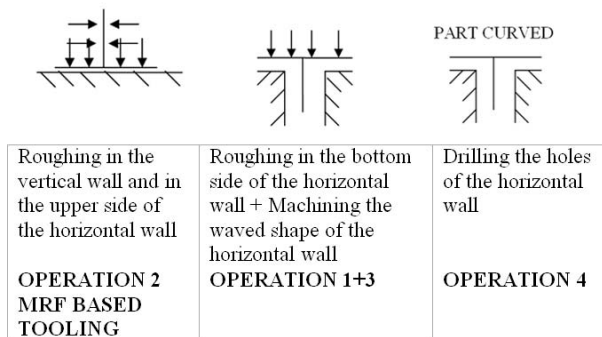


Figure 3. Complete process of manufacturing the titanium T-shape aeronautic stringers using the MRF based tooling

The MR fluid based tooling is based on a bath configuration where the MR fluid is in direct contact with the workpiece. The workpiece is partially immersed in to a tank containing the MR fluid and is properly located in the fixture thanks to reference pins. The MR fluid which in the liquid state has the consistency of viscous oil increases its mechanical strength under the influence of a magnetic field within fractions of a second and holds gently but securely the workpiece in position. The MR fluid also adapts to small geometrical fluctuations and can thus be used to apply uniform holding forces even on workpieces of large surface areas. Slight shape inaccuracies or changes in shape are compensated.

In order to get the maximum magnetic flux density in the MR fluid, it must be in direct contact with the magnetic circuit and its thickness must be as small as possible. The latter obliges to design a tooling which geometry is very similar to the workpiece's geometry.

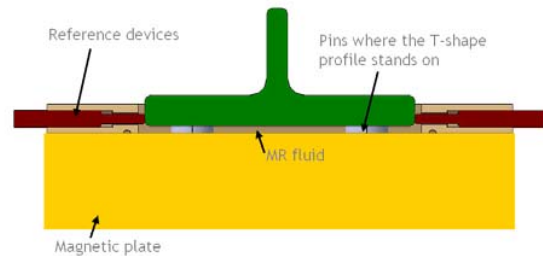


Figure 4. Conceptual design of the MRF based tooling

SUCCESSFUL MR FLUID DEVELOPMENT

Magnetorheological fluids are suspensions of tiny iron particles which are finely distributed in a carrier liquid – usually mineral oil or silicone oil. When a magnetic field is applied, the iron particles arrange themselves along the magnetic lines of force and thus change the flow behavior of the fluid. As the field strength increases, the fluid transforms into a gel-like solid mass. The use of special chemical additives prevents premature sedimentation and ensures that the MR Fluid has a long service life. The application-relevant properties of the MRF in terms of the mechanical strength in the magnetic field and the fluidity without field can be adapted by the composition. Main parameters of influence are the iron particle concentration, the particle size distribution, the carrier liquid, etc. [10] [11]

In the usual applications of magnetorheological fluids, such as vibration damping, the mode of flow plays a major role, and the magnetic field is used to control the flow resistance as the fluid flows through an opening [12], [13]. When a workpiece is held by immersion in the MR Fluid, on the other hand, the main forces that occur are shear forces and compressive and tensile loads.

In order to support large parts securely, the MR Fluid needs to have a particularly high holding strength. An important variable in this context is the yield point, which determines the force which has to be applied to cause a material to flow. The yield point increases with the strength of the magnetic field applied – and along with it the holding strength of the magnetorheological fluid. If the MR Fluid exhibits a high yield point, only a small part of the workpiece needs to be immersed in the fluid. This increases the area that can be machined. Depending on the geometry of the part being machined and the degree to which it is immersed, tensile and compressive forces of various strengths act on the MRF in addition to the shear force.

In order to develop a suitable MR Fluid, the holding strength first has to be measured under different loads. For this purpose, the Fraunhofer ISC's competence team Smart Materials initially developed a special testing device with which the holding strength as a function of the magnetic field strength can be determined against the shear loads acting on a test plate. Using this