Concept design of a 5-axis portable milling machine for the in-situ processing of large pieces

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Abstract

For conventional machine tools the work piece is placed inside the structure and therefore its overall dimensions determine the size of the workspace and with it also the general size of the complete system, which leads to extreme disproportions between theoretically appropriate and actually needed system size. In large pieces this results in even larger machines presenting technical and practical issues well known and described in the state-of-the-art. An alternative to solve this issue is to get rid of the dogma "work piece inside the machine" and replace it by the principle "small machines on large work pieces" [1][2].

This paper presents and discusses a new paradigm of portability and proposes the basic design of an advanced portable machine for in-situ and on-the-part milling of large components. More specifically, the machine shall be able to machine features larger than itself without continuity issues and automatically by means of an array of sensors and built-in CAM reprocessing capabilities, in close contact with the CAD file of the piece. For enhanced functionality, the machine targets usual engineering materials (steel, aluminium and composites) and processes (drilling and milling) with mid-to-high removal rates with a fully-flexible 5-axis configuration. Said machine will become the backbone of a set of R&D efforts in the field of miniature and portable machines with a view to developing sound solutions for the limitations of portable machines in terms of part and feature precision, machine clamping on the part and process capabilities with limited machine sizes.

1 Background and portability as a new paradigm

The basic idea behind the new paradigm proposed in this paper is to use autonomous machining units which are placed locally at the work piece using it as machine foundation. The dimension of these units and their performance no longer depend on overall dimensions but on the geometry which is to be machined. This approach predominantly follows the principles of miniaturisation, freedom through mobility (whether it moves by itself or is displaced) and flexibility (in processes and materials), and utilisation of synergies.

Moreover, this “small machine on large work piece” approach leads to improvements in the followings aspects of the machine and process:

Mobility: meaning both the general transportability of production systems to the site of operation and close to the work pieces, and the placement of the machinery on/at the work piece. Miniaturization: a general reduction of system size. Adaptivity: defined as a short term modulation of machine properties to match production process requirements with the capabilities of the executing system. Mutability: defined as the long term modifications on production systems. Multifunctionality: especially work pieces with complex geometric features can be machined much faster and more efficient through complete machining on multifunctional machine tools because of elimination of work piece transport between different work stations. Specialisation: specialised production technology may be provided with process fitted equipment, thus ensuring very effective and efficient application of operating devices.

2 The fully-portable, five-axis, miniature milling machine

2.1 Machine concept

The machine proposed to establish the limits of this new paradigm is a five-axis, miniature milling machine based on a serial kinematic architecture. This kinematic solution has been chosen because it shows remarkably homogeneous stiffness behaviour for every possible machine orientation and process combination. The ability to easily configure and control the work volume and the simplified error control and calibration procedures also contribute to favour this kinematic over the parallel-machine architecture, even if the latter can show better stiffness-weight ratios.

Over the state of the art [3] [4] [5] , this portable machine can perform both mid-duty milling and drilling operations in a five axis configuration. To achieve this, three stacked linear axes are included, which carry a two axis rotating system holding the spindle, in a compact machine envelope of 1200 x 1200 x 1200 mm. The work volume of the machine is 340 x 300 x 220 mm with A and C axes ranging from -40º to 100º and 0 to 420º, respectively.

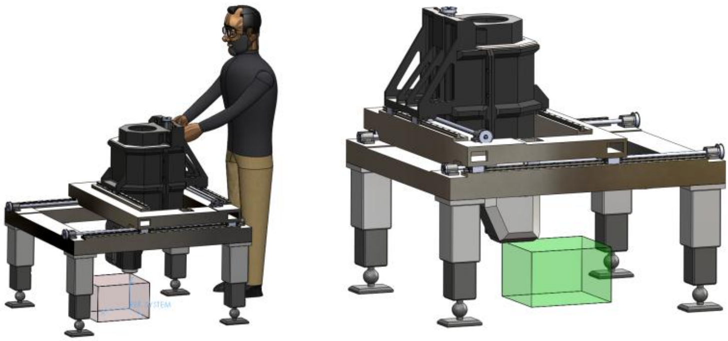

Figure 1: The concept design of the machine (man portrait for scale purposes)

2.1 The spindle

The machine is equipped with a 9 Kw@10.000 rpm synchronous spindle which allows the machine to cover mid-duty roughing operations in conventional steel (at low speed and high torque) and operations in aluminium components (at higher speeds and high power). With the two axes system right behind directly holding the spindle, the process flexibility is therefore ensured.

2.2 Sensors

This paradigm makes the machine closer to a free robot than a conventional machine and thus new needs appear for external referencing (navigation) and internal referencing (feature recognition within the workpiece).

For internal referencing, the machine is equipped with a laser scanner with a typical precision of 50 µm, combined with a touch probe for redundancy and finer data acquisition.

For navigation, the machine relies ultimately in a laser tracker to define its position in space although several more economic technologies are being studied for smoother integration in industrial environments, such as the identification of scanned-part features in the cad, or the use of bespoke fiducials.

3 Advanced process capabilities

The machine is intended to perform advanced manufacturing according to three different scenarios.

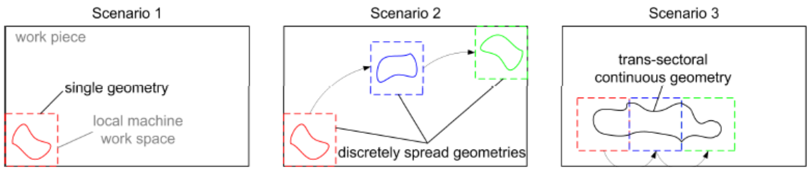

Figure 2: The three machining scenarios considered

For scenarios 2 & 3, the machine uses both global and local referencing capabilities in the following way:

Step1: Fix the relative position (machine – workpiece)

Step2: Scan the workpiece zone within the machine work space

Step3: Identification of the workpiece comparing the 3D data to the CAD file, using singular features or previously located patterns for fitting

Step4: Definition of a reference coordinate system related to the machine axis

Step5: Definition of the tool path for the current machine position (CAM module)

Step6: Perform the machining operation

Step7: Back to first step

4 Conclusions

This paper presents a fully-flexible 5-axis miniature milling machine as a platform to test the functional and productive capabilities of this novel portability paradigm. The theoretical capability assessment and the experimental validation will be performed in late 2013 and 2014.

References:

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