Multibody modelling of a flexible 6-axis robot dedicated to robotic machining

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As robots are increasingly involved in industry, robotic manufacturing techniques arise as well in order to replace their conventional counterpart. Back in the seventies, robots were first used for assembly, painting and spot-welding applications, mainly for car industry. Advances in robotics led to improvements in the robot internal mechanics and in their control to be able to address more challenging applications such as friction stir welding, jet cutting, casting, etc...

This paper focusses on robotic machining, which consists in using an industrial robot as a machine tool, and more particularly on the modelling aspects. This technology combines the agility, the large workspace and the flexibility of a robot without the dreadful cost of a CNC machine. Robotic machining may therefore represent an alternative for finishing operations, especially for large workpieces coming from aeronautics or foundry industry. Nevertheless, as any technology, robotic machining encounters some limitations coming from the lack of joint stiffness when attempting the milling of hard materials. This drawback may have severe implications for the process resulting in a depletion of the machined surface quality. Even more disturbing, with rather low eigenfrequencies (around 10 Hz), process forces may cause the robot to excessively vibrate leading to unwanted motions of the TCP (*Tool Center Point*). This phenomenon, so-called chatter, is one of the primary reasons that prevent robotic machining to spread in industries. Consequently, it is necessary to build models of the whole process, on the one hand, to understand the origins of such disturbing phenomena and on the other hand, to develop methods to prevent them or minimise their effects [1].

The modelling of the whole robotic machining process is especially addressed in this paper. This work is part of a project at the university of Mons, in Belgium, aiming to find the best robotic machining operating conditions by relying on a model and real experiments. In order to build a simulation environment dedicated to robotic machining, two in-house frameworks, `EasyDyn` and `Dystamill`, were coupled. `EasyDyn` is a `C++` multibody library, developed for the simulation of multibody systems [2]. The kinematics of the system is embedded into the program and in parallel, the user describes the forces exerted on each body. From this information, the framework is able to derive and integrate the equations of motion of the system from the application of the d'Alembert's principle. `Dystamill` is a `C++` milling routine, able to compute the cutting forces coming from the process. It was first developed taking into account the machine tool dynamics [3] and features an approach enabling the update of the machined surface.

Back in the beginning of the project, useful modules of `Dystamill` were included inside the `EasyDyn` multibody library to form the robotic machining simulation environment. It was first tested and validated on machine tool examples [4].

Continuing the simplified model, developed in [5], the robot was extended to six degrees of freedom as most of the industrial robots. Dimensions of the model were inspired from the Stäubli TX200 robot since experimental data related to cutting forces were available. A dynamic model of the robot requires the knowledge of each link mass, inertia tensor and the location of each centre of mass. Those properties were indirectly inferred from the manufacturer CAD models. Indeed, the provided 3D models showcased solid parts that were completely redesigned in order to capture their internal shapes, allowing a better estimation of the dynamic properties. Motor mass and positions were also taken into account and the load of the spindle was naturally added to the model. The robot extended model ended up with the definition of 10 bodies: the base, the shoulder, the main arm, the elbow, the forearm, the wrist, the flange, the spindle support, the spindle and the cutting tool (Figure 1).

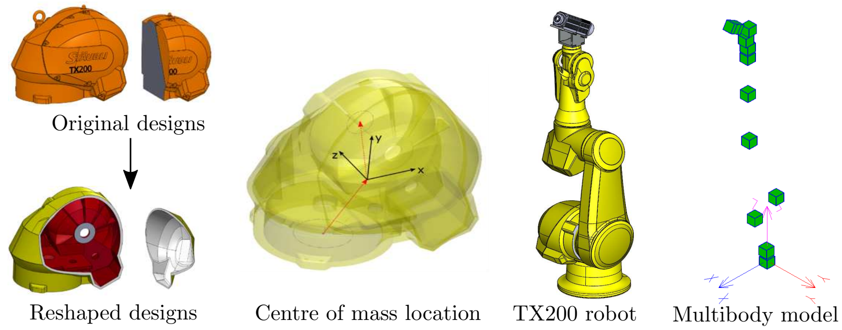

Fig. 1: Modelling steps of the robot dynamic model

Then, the robot model was enhanced with the inclusion of joint compliance (and damping), the latter being the primary cause of milling instabilities in robotic machining. Stiffness and damping characteristics had to be collected from robots having an equivalent payload in the literature. Four different modellings were progressively built afterwards:

1) dynamic robot model without gravity;
2) dynamic robot model with gravity compensation;
3) dynamic robot model with gravity compensation and joint orthogonal bushings;
4) dynamic robot model with gravity compensation, joint bushings and backlash representation.

Each model was finally subjected to cutting forces. Unsurprisingly, the dynamic robot model including the backlash representation was able to mimic quite well the cutting force signal coming from experimental data, as depicted in Figure 2 for a straight line into an aluminium plate. Further details and analyses will be provided in the paper.

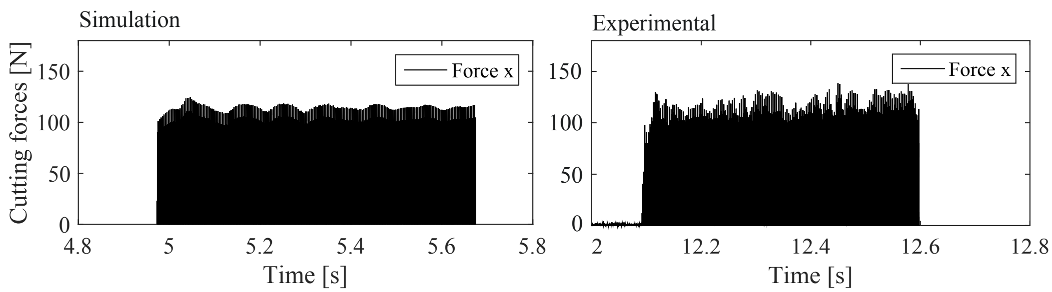

Fig. 2: Comparison of cutting forces (bushings and backlash included)

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