Process Design and Automation for Large Volume Hybrid Manufacturing Robot with High Accuracy and Quality

F. Crivelli, A. Steinecker, P. A. E. Schmid

A new machine combined with innovative manufacturing processes and technology bringing the advantages of 3D printing to large volume fabrication.

Industrial fabrication based on 3D printing or hybrid processes that combine additive (AM) and subtractive manufacturing (SM), is growing. Important sectors such as aerospace, energy industry, automotive, shipbuilding, oil & gas, etc demand large, high quality components. These branches could considerably benefit from AM and *hybrid manufacturing* (HM) technology; however, available machines are limited to small workspace and today there is no solutions for large parts. A large workspace (>200 m^3) implies multiple challenges preventing a simple "scaling up" of existing technologies [1]. The European Project KRAKEN [2] addresses to this challenge with the objective of making 3D printing and rapid prototyping compatible with large volumes and finding an economically sustainable solution to guarantee high accuracy over large workspaces. The resulting machine is composed by a 6 degrees-of-freedom (DOF) manipulator (NJ130, Comau S.p.A., Torino, I) mounted on a 3-axes crane. The crane guarantees a large workspace (22x5.5x3.5 m), while the manipulator provides high agility. The end-effector was designed as a hybrid head including a permanently mounted spindle for SM completed by a retractable mechanism with automatic quick tool change, for easily switching from resin to metal AM.

Figure 1: Climb-up HM process, (left) Resin AM; (right) Milling.

Within the KRAKEN consortium several technology bricks were elaborated. A new machine-dispensable resin was developed. The 2-component polyurethane paste (ALCHEMIX PU3720A/B, Alchemie Ltd, Warwick, UK) cures rapidly and once cured it can be machined easily. A resin dispenser with deposition rate up to 120 kg/h was developed. Furthermore, *wire arc additive manufacturing* (WAAM) was included for aluminium 3D printing with deposition rate up to 1.5 l/h; and *arc spray metallisation* based on zinc alloys was developed to integrate metallic substructure and surfaces within resin parts. Traditional SM process has been adapted based on a *climb-up* methodology, specially designed for planar layer-by-layer and direct 3D freeform production (2 mm depth of cut and 6m/min speed for standard processes and up to 750 mm/min for high accuracy of <0.1 mm geometric error). Such hybrid process allows good finishing on difficult-to-reach areas as well as better controlling thermal stresses and deformations.

CSEM plaid a key role in developing the KRAKEN software suite, which provides user interaction combined with hardware integration, control tools and automation functionalities. This guarantees an efficient process flow from 3D models to manufactured parts. New computer aided manufacturing (CAM) tools including planar horizontal layer strategies and new direct 3D freeform approaches have been developed in an intuitive user interface dedicated to generation and simulation of HM tasks. High geometric accuracy over the large workspace, is guaranteed based on *laser tracking technology* [3]. The laser tracker (AT960, Leica/Hexagon MI, Unterentfelden) provides real-time (1 kHz) measurement of absolute position and orientation of machine components and end-effector. The control software designed by CSEM integrates the laser tracker feedback in the robot motion control, to dynamically correct the deviations with respect to the reference trajectories. The metrology system is fully integrated within the KRAKEN software allowing automated calibration and continuous monitoring of the machine. Laser scanning technology combined with the laser tracking system provides in-process geometry validation of the parts [3]. The KRAKEN machine was used to manufacture a mock-up of a Pininfarina (S.p.A., Turin, I) car design. The task was successfully completed based on climb-up approach, validating this novel HM process, as well as verifying the new CAM functionalities and the laser tracker-based robot controller. 5-DOF resin dispensing combined with arc spray metallisation has been validated by Acciona (S.A, Madrid, S) in the fabrication of hybrid lining panels for road tunnels, which embed electrical wiring for the emergency lighting. CRF (Torino, I) is testing the deposition of metals on composite materials to simplify assembly. Moreover, the KRAKEN machine was used to mill a wood mock-up of 90 m^2, installed in a museum in Qatar; to machine a big composite beam (Acciona); and polishing a windmill blade for a renewable energy company.

Figure 2: The KRAKEN robot machining the Pininfarina car mok-up.

This project received funding from the European Union's Horizon 2020 research and innovation programme (No 723759).

[1] F. Crivelli, *et al.*, "An all-in-one robotic platform for hybrid manufacturing of large volume parts," In: Ratchev S. (eds) Precision Assembly in the Digital Age, IPAS 2018, 2019.

[2] https://krakenproject.eu

[3] F. Crivelli, V. Baumann, *et al.*, "Large volume hybrid manufacturing based on absolute laser tracking technology ", In: Proc, of the 1st ICWNDT, 2018, in press.