

Based on the derived hybrid layout, sequential work processes and emergency scenarios were assessed.

3.1 Normal Operation (Automated Process)

The ATC robotic arm automatically changes to the appropriate tool at the stand and autonomously performs the moving, fastening, and detaching of the crucible and mold.

3.2 Emergency Intervention (Manual Process)

A simulated robot malfunction was introduced. The standby MSM accesses the primary workspace to safely retrieve components held by the robot or mechanically tow the robot's joints to a maintenance zone.

Throughout this assessment, spatial constraints, reachability, and potential collisions between the two remote devices and surrounding structures were rigorously analyzed.

4. Results and Conclusions

This study successfully validated the spatial and kinematic applicability of the hybrid remote fabrication system through a comprehensive digital mock-up assessment.

The assessment results demonstrated that integrating the ATC system minimizes the need for auxiliary equipment, securing a sufficient working volume for the MSMs and the robotic arm to coexist without mutual interference. The process sequence evaluation confirmed that the robotic arm possesses adequate reachability to access all target points around the casting apparatus during normal operations. Furthermore, emergency scenarios verified that the MSMs encounter no spatial constraints when intervening within the robot's operational radius for maintenance tasks.

In conclusion, this digital mock-up study proves the applicability of a complementary remote manufacturing system that achieves both high productivity via automation and robust reliability via manual intervention. The optimized layout and kinematic assessment data derived from this research will serve as fundamental references for future hardware integration testing in the actual KAERI mock-up facility.

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