DEVELOPMENT STATUS OF IN-VESSEL COMPONENTS INSPECTION AND PIPE MAINTENANCE ROBOT FOR K-DEMO AND FUSION EXPERIMENTAL DEVICE

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1. INTRODUCTION

The operating environment of a fusion reactor, such as the Korean Experimental Fusion Reactor (K-DEMO), involves harsh conditions, including high radiation, vacuum, and limited accessibility, which poses considerable technical challenges for maintenance. This challenge requires remote maintenance (RM) techniques. Existing maintenance methods are limited by safety hazards and space constraints, further highlighting the importance of robotic handling. Many countries have developed robotic systems to operate in harsh environments. However, depending on the environment setting, robotic systems often suffer from shortcomings in terms of precision, adaptability, and robustness when exposed to the fusion reactor environment. Therefore, advanced robotic solutions tailored specifically for fusion environments are required to address these limitations effectively.

This research presents recent advancements in RM technologies for K-DEMO and a fusion experimental device, specifically focusing on a newly developed robotic system for internal vessel inspections and a laser-based robotic welding system designed for precise pipe maintenance. Our study is focus on the enhancing the current fusion reactor maintenance scheme by integrating robotic technologies capable of operating under harsh environment such as high radiation, high temperatures, and complex space constraints. This research provides substantial improvements to existing maintenance methodologies, with particular attention given to performance reliability and operational precision.

In section II, we introduce the development of a Multi-Purpose Deployer (MPD) robotic system optimized for internal inspections. Subsequently, section III discusses the advanced laser-based welding robot developed to overcome limitations inherent in conventional pipe maintenance methods

2. IN-VESSEL COMPONENTS INSPECTION ROBOT FOR FUSION EXPERIMENTAL DEVICE

We designed a robotic arm system as the MPD This arm system equipped with 13DOF, an approximate length of 11 meters, and an optimized link length to KSTAR's equatorial port. We target minimizing the robotic arm's cross-sectional size to check the minimum port size requirement. The robotic arm is equipped with a camera and gripping modules, allowing inspections and simple tasks. This research provides insights into reactor design improvements, specifically addressing accessibility and maintainability under complex reactor conditions.

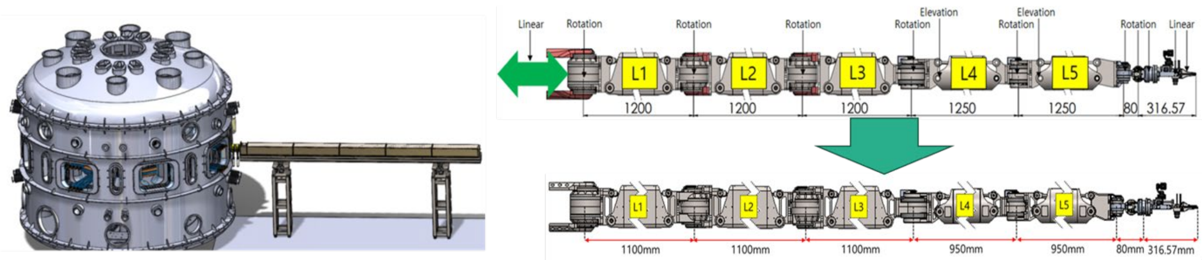

Figure. 2 The overview of the robotic arm system and a length optimization of the robotic arm based on the reachability

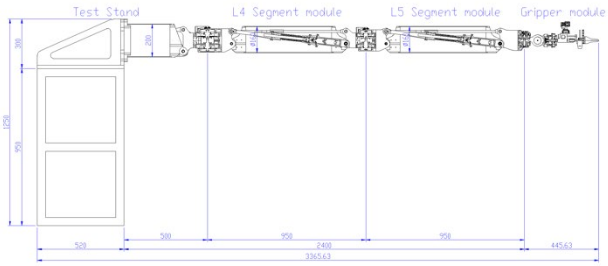

Figure. 1 A design of substructure of robotic arm currently in production

Currently, fabrication of the robotic arm substructures is underway. In future steps, the control algorithm will be further iterated based on comprehensive testing, system reliability assessment, and motion capture feedback to ensure robustness under real reactor conditions.

3. PIPE WELDING ROBOT FOR K-DEMO

In addition to inspection capabilities, effective RM also requires precise maintenance technologies, especially for internal pipe structures. This necessity led to the development of an advanced robotic welding solution, which is discussed in the following section. Existing The maintenance of internal pipe structures within fusion reactors requires highly accurate welding technologies due to complex geometries and limited operational access. TIG welding methods present sticking risks and restricted applicability in curved internal pipes. To overcome these limitations, we started the research of a laser-based welding system specifically designed for operating in the K-DEMO's internal pipes.

Our pipe welding robot features a compact, flexible laser welding head, optimized for internal pipe welding applications. The system targets curved pipes with diameters of 80 mm, with 5mm thickness. The device is currently ready for testing and will serve as a reference for future developments, particularly regarding the feasibility of precise welding operations within curved pipes. We plan R&D to reduce a capable banding radius from 1300mm to 600mm.

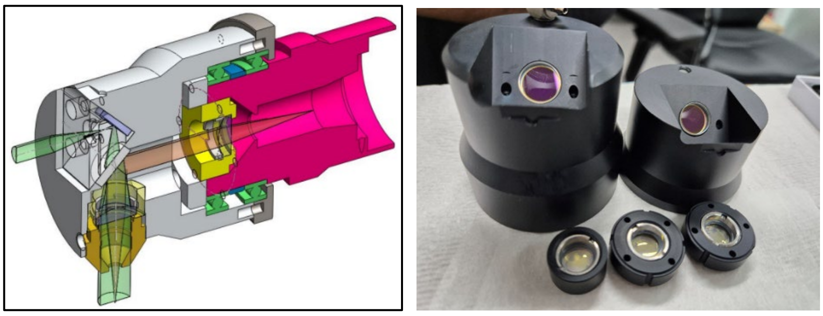

Figure. 3 A welding device head design and a part of mock-up

4. A CONCLUSION AND FUTURE WORK

In this research, we presented recent developments in essential robotic technologies designed specifically for the RM related fusion experimental devices. The Multi-Purpose Deployer (MPD) robotic arm demonstrated potential in performing critical inspection tasks within confined reactor spaces, enabled by structural optimizations validated through simulation and initial experimental evaluations. Additionally, the newly designed laser-based pipe welding robot showed significant improvements in weld quality, operational efficiency, and adaptability to complex internal pipe structures compared to conventional welding methods.

Future work will involve rigorous full-scale tests of both robotic systems within representative simulated environmental conditions closely approximating actual reactor operation. Through the step-by-step approach, we gather the fundamental data for operating robot in a little lower than real reactor condition and upgrade each component to more suitable to the harsh environment in DEMO reactor. These evaluations will focus on verifying operational accuracy, reliability, and overall system robustness. Through comprehensive assessments, we aim to quantify the specific maintenance times required, further optimize system performance, and establish standardized operational procedures. Ultimately, these advancements will contribute to the long-term reliability and efficiency of fusion reactor maintenance, enhancing the feasibility of K-DEMO's practical implementation.

ACKNOWLEDGEMENTS

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