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Simulation based assembly and alignment process ability analysis for line replaceable units of the high power solid state laser facility

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HIGHLIGHTS

- Discrete event simulation is applied to analyze the assembly and alignment process ability of LRUs in SG-III facility.
- The overall assembly and alignment process of LRUs with specific characteristics is described.
- An extended-directed graph is proposed to express the assembly and alignment process of LRUs.
- Different scenarios have been simulated to evaluate assembling process ability of LRUs and decision making is supported to ensure the construction millstone.

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ABSTRACT

Line replaceable units (LRUs) are important components of the very large high power solid state laser facilities. The assembly and alignment process ability of LRUs will impact the construction milestone of facilities. This paper describes the use of discrete event simulation method for assembly and alignment process analysis of LRUs in such facilities. The overall assembly and alignment process for LRUs is presented based on the layout of the optics assembly laboratory and the process characteristics are analyzed. An extended-directed graph is proposed to express the assembly and alignment process of LRUs. Taking the LRUs of disk amplifier system in Shen Guang-III (SG-III) facility as the example, some process simulation models are built based on the Quest simulation platform. The constraints, such as duration, equipment, technician and part supply, are considered in the simulation models. Different simulation scenarios have been carried out to evaluate the assembling process ability of LRUs. The simulation method can provide a valuable decision making and process optimization tool for the optics assembly laboratory layout and the process working out of such facilities.

1. Introduction

The large optics-mechanical modules are very important components of the very large solid state laser facilities with higher energy output, for example National Ignition Facility (NIF) [1,2], the Laser Megajoule (LMJ) [2,3] and SG-III facility (Fig. 1) [4–7]. These modules are also called line replaceable units (LRUs) [2,8], which typically include a mechanical housing, laser optics (glass, lenses, or mirrors), actuators and kinematic mounts. During the life cycle of the facility, i.e. the construction, use and maintenance, LRUs and their parts are treated, assembled, aligned, and tested in other separate laboratory[1,9], such as optics processing laboratory (OPL) and optics assembly laboratory (OAL), prior to installation in the beam path infrastructure. The rigorous cleanliness level is required in OPL and OAL, where both the commonality and versatility are achieved to handle the various LRU types. The LRUs should be delivered into the laser bay (LB) without damaging their strict cleanliness and precise alignment.

The construction of the high power solid state laser facilities faces many risks including cost, time, technology and engineering aspects [1,10]. The production of the LRUs is constrained by a very tight schedule and budget concerning many factors, such as the space of OPL/OAL, supply of the optic mirrors and many large size complex custom equipments. Owning to the cleanliness and area requirements of the space, the LRUs and their individual components will be limited to expose and store in the building. So the production activities in the LRU assembly area must follow a

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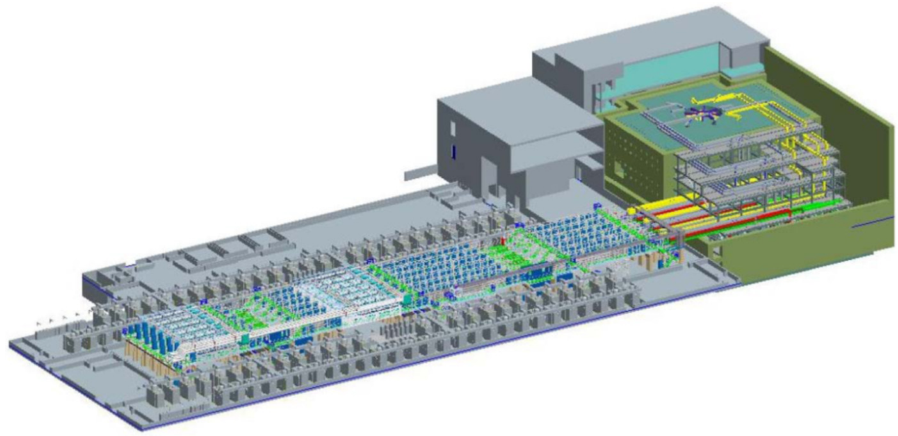

Fig. 1. The overall layout of the SG-III laser facility [4,5].

just-in-time (JIT) processing and clean transfer to the areas where the optics will be used [1,11].Optimization and validation of the assembly and alignment ability for LRUs production is a complex challenge during the lifetime of all high power solid state laser facilities. A decision-analysis tool is required to identify risks, allocate resources, schedule technicians, and assure that the construction schedule can be met within given time, resource, and budget constraints.

Discrete event simulation (DES) is a useful tool for identifying and mitigating potential bottlenecks, resource conflicts, and scheduling issues in manufacturing industry [12]. It has been successfully applied in production analysis of automobiles, ships and aircraft [13]. In the case of large components/modules for high power solid state laser facilities, the assembly and operation process is akin to a manufacturing production facility except for distinct constraints, and can benefit from DES. In order to assure the LRUs supply for the NIF milestones, a simulation model named OABSIM for LRUs production had been developed by using commercial software ProModel [11]. The model simulated the production steps, required resources, and material flow of LRUs production. The overall goal was to ensure that the "leaned" procedures were adequate to meet the overall activation schedule. But no more details were mentioned about the complex resource and parts constraints. The DES tool was used in the ITER Hot Cell design for operability analysis [14]. Effects of parameters such as human resource shift patterns, equipment mean time between failure and random variability in process times on overall Hot Cell productivity had been studied, which served as a valuable tool to determine and improve the overall performance of the Hot Cell design scheme.

Many software systems are used in the process of fabricating, assembling, and tracking the hundreds of thousands of parts for the NIF LRUs [15]. By taking the LRUs of disk amplifier system in the SG-III facility as an example, the analysis of assembly and alignment process ability based on discrete event simulation is the main topic in this paper. Taking into account the operator shift patterns, the supply schedule of the mirror components, the working resources and the area of OAL, the assembly and alignment process models of LRUs are described. Based on the layout of optics assembly laboratory, the simulation models are setup and the constraints are presented. The disk amplifier subsystem is used as the example to illustrate the process ability analysis under the above constraints. Our works can contribute a useful tool for the schedule planning, forecast and optimization of LRUs production for high power solid state laser facilities now and in the future.

2. Assembly and alignment process modeling

2.1. Process outline and characteristics

There are thousands of LRUs comprised of more than ten thousands serialized parts that make up the high power laser facilities in different sections of the beam path [1,16]. The assembled LRUs weigh up to about two thousands kilograms, and are about the size of a phone booth [17]. Fig. 2 shows some LRUs commonly used in the facilities [1]. The general components of LRUs are mechanical parts and optic parts, which usually go through three phases before come into use in the beam path, i.e. cleaning, offline assembly and online alignment in laser bay (Fig. 3). During the whole process, different cleanliness levels are required in the corresponding areas, whose cleanliness levels vary from class 100 to class 100000.

The mechanical parts for all LRUs usually have the similar cleaning process, such as ultrasonic and high pressure spray system, but vary greatly in size, geometry, surface finish, and material. The range in size can be from machine screw parts to frame-like mechanical structures as long as ten feet [18]. The optical parts of different LRUs have distinct cleaning and optics processing procedures, where a wide variety of specialized equipments are required.

After being cleaned, the mechanical parts will be assembled to form a support frame which is used to hold the different optics parts in OAL, such as mirrors and Xe flash lamps. The optics parts are installed to LRU frame by insertion devices which pick up and precisely position the optics at various angles and positions. The whole LRU will then undergoes a rigorous set of inspections and verifications to ensure that it will meet requirements for wave front, alignment, cleanliness, and functionality of actuators and other electronic components by mean of several optics and mechanical diagnostic systems [9,19].

Once assembled and tested, the LRU is put into the canisters, which are portable clean rooms that carry the LRU to laser bay. An automated guided vehicles (AGV) or manually controlled forklift are used to transport the canisters to the location where the LRUs will be inserted into the main frame and adjusted to align the beam path [20]. The online insertion and alignment process usually consist of pre-position, precision position, lift and adjustment sub-process.

From the viewpoint of production, the assembly processes of LRUs have many distinct characteristics compared with the traditional mechanical products. The production environment needs to be rigid cleaning surroundings in different areas. In order to