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Assessment of different lifting devices for the shipping bays for DONES main building

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ABSTRACT

During the installation and maintenance phase of IFMIF-DONES (International Fusion Materials Irradiation Facility-DEMO Oriented Neutron Source), several components need to be transported vertically between different floors inside the DONES main building. There are totally four shipping bays inside the main building, two of which are mainly responsible for components transportation. The lifting devices in the shipping bays should be carefully selected based on the requirements of components, including their sizes, weights, shapes, activation status, shielding requirements, human escorts and transportation routes. Considering these requirements and the building information, five possible lifting devices are proposed, namely parallel ropes lift, heavy load storage and retrieval machine, rack and pinion lift, upside-down scissor lift as well as rigid chain lift. The optioneering method is applied to assess the different lifting devices with the help of weighted criteria. As a result, parallel ropes lift, heavy load storage and retrieval machine and rigid chain lift are assessed as the most appropriate lifting devices in the shipping bays for DONES main building. A market survey is carried out on these three kinds of lifting devices. At the end of this paper, the principle sketches of the rigid chain lift inside the shipping bay are shown including the transport platform.

1. Introduction

IFMIF-DONES (International Fusion Materials Irradiation Facility-DEMO Oriented Neutron Source) is one of the most important facilities in the EUROFusion Roadmap [1]. In the scope of DONES facility, about 14 MeV neutron flux will be created in order to irradiate the material under the same condition as in the future fusion power plant DEMO (Demonstration power plant). Then the irradiated materials will be sent to labs for performance testing.

The DONES facility is composed of several buildings in one site plot, including a main building and several auxiliary buildings for gas, water, electricity supplement etc. During the installation and maintenance phases of DONES, various kinds of components are going to be transported between different buildings and inside buildings. In the DONES main building, there are four shipping bays for vertical transportation of components from the basement to the third floor. Until now, shipping bays 2 and 4 are mainly planned for components transport, while there are still no specific plans for transportation through shipping bays 1 and 3. Fig. 1 shows the drawing of the ground floor of the main building. The four shipping bays are marked with green boxes. Only shipping bay 1 is located on the north side, the other three shipping bays are on the south. The four shipping bays have different dimensions: shipping bay 1 has a dimension of 9700 mm*10000 mm, shipping bay 2 is 9700 mm long and 7430 mm wide while shipping bay 3 has a length of 10000 mm and width of 7430 mm, shipping bay 4 has a dimension of 10000 mm*7430 mm.

In order to find appropriate lifting devices for shipping bays 2 and 4, the flow of materials through these two shipping bays is analyzed. Based on the flow of materials, the requirements of the corresponding lifting devices are collected. Considering the requirements and building information, five possible lifting devices are proposed, namely parallel ropes lift, heavy load storage and retrieval machine, rack and pinion lift, upside-down scissor lift as well as rigid chain lift. For the purpose of choosing the most appropriate lifting device, the optioneering method is applied to five proposals. Firstly, seven groups of main criteria are proposed, while each has different numbers of sub-criteria. These sub-criteria are then assigned with different weights according to their importance defined through expert interviews. Since the weightings are defined by experts, which is not totally objective, it should be noted that the results are dependent on the experts' personal preferences. The results may differ if different group of experts are interviewed. Finally, each lifting device is evaluated regarding each sub-criterion. The weighted sum of scores for each device is compared between the proposed five lifting devices. Furthermore, market research is carried

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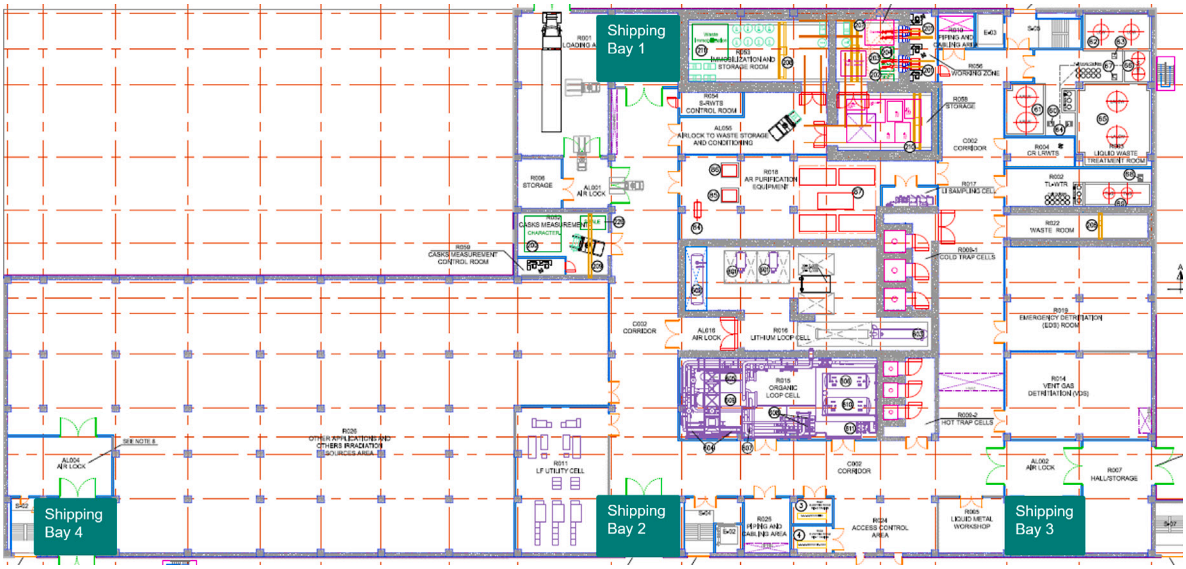

Fig. 1. Drawing of the ground floor of the main building.

Table 1
The critical components through shipping bay 2.

Components	Length, mm	Width, mm	Height, mm	Weight, kg
Component 1	1320	1905	3200	10676
Component 2	1658	465	6845	504

Table 2
The critical components through shipping bay 4.

Components	Length, mm	Width, mm	Height, mm	Weight, kg
Component 3	6166	1600	2523	17000
Component 4	6978	1600	2523	17000
Component 5	7034	1600	2523	8000
Component 6	7034	1600	2523	8000
Component 7	7034	1600	2523	8000

on for the well-evaluated lifting devices. Their principle sketches are shown at the end of this paper.

In the following, Section 2 analyzes the flow of materials through shipping bays 2 and 4 and defines their requirements on the lifting devices. In Section 3 the optioneering method is introduced and applied, while Section 4 shows the market research results of the well-assessed lifting devices. In Section 5 the principle sketches of rigid chain lift are depicted.

2. Flow of materials and requirements

In this chapter, the critical flow of materials through shipping bays 2 and 4 are listed with the components' dimensions and weights information. Due to the large dimension of the critical components through shipping bay 4, the size of shipping bay 4 needs to be modified, which is discussed in 2.1. Based on the flow of materials, the technical requirements on the lifting devices in both shipping bays are captured in 2.2.

2.1. Flow of materials

Among all the components that will be transported through shipping bay 2, two of them are critical. Component 1 is the heaviest component while component 2 has the largest dimension. Their information is listed in Table 1.

Since the biggest component through shipping bay 2 is smaller than the shipping bay, the size of shipping bay 2 does not need to be modified. All the components will be transported by omnidirectional mover and pallet, the weight of the total transport unit of component 1 will be almost 20 tons. Thus, the lifting device in the shipping bay 2 should have a minimum payload of 25 tons considering the weight of the transport platform and safety factor.

The information about critical components through shipping bay 4 is listed in Table 2.

The heaviest components through shipping bay 4, components 3 and 4, are about 17 tons. Taking the weights of the omnidirectional mover and pallet into account, the total weight will be about 35 tons. Thus, the payload of the lifting device in the shipping bay 4 should be approximately 40 tons.

Additionally, components 3 to 7 will be transported with a transport frame, which extends the dimension of 600 mm*90 mm*400 mm. Since the components are narrow and tall, it is specified to transport them along the length direction of components, which means the width of shipping bay 4 is not enough for the transportation of these critical components (7034 mm+600 mm>7430 mm). Thus, the width of shipping bay 4 needs to be extended.

2.2. Requirements

Except for the dimensions and weights of components to be transported, there are also other requirements that the lifting devices need to be satisfied:

- The lifting devices should have four stops, from the ground floor to the third floor.
- The conveying height from the ground floor to the third floor is about 25 m.
- The height of the first floor is 9 m, the second floor 18 m, while the height of the third floor is 25 m.
- There are seismic pits in the basement. The installation of the lifting devices should make the effect on the seismic pits as little as possible.
- The throughput of the lifting devices should be less than 10 per hour.
- The operation days of lifting devices are 30 days annually.
- The acceleration/deceleration of lifting devices during operation should be as small as possible due to sensitive components.
- During the loading and unloading process, the transport platform should be as stable as possible, and the step between the platform and floor should be less than 5 mm.

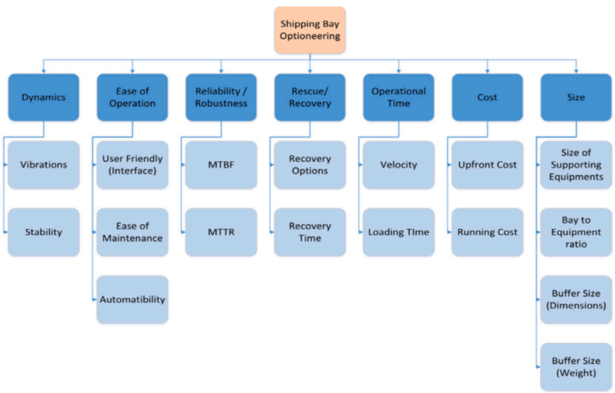

Fig. 2. Hierarchy of selected criteria.

- There will be no radiation in the shipping bay 4. The radiation in shipping bay 2 will be less than 100 microsieverts per hour.
- There will be no human transportation with these lifting devices

Based on these requirements, five possible lifting devices are proposed, namely parallel ropes lift, heavy load storage and retrieval machine, rack and pinion lift, upside-down scissor lift as well as rigid chain lift. In order to find the most appropriate lifting device, the method of optioneering is introduced in the next section.

3. Optioneering

Optioneering is a well-known and widely used method for identification, assessment and definition of different possible options for problem-solving. The aim of optioneering is to find the best option in a predefined situation. It can be used in various areas, such as construction, engineering design etc. To start optioneering, it is important to find appropriate experts to carry out expert interviews. In this study, three experts in the field of material handling and logistics are found. All of them have many years of working experience (not only research experience but also industrial experience) in this field and are responsible for designing different kinds of material handling equipment in their work. Thus, they are qualified to be interviewed and help assess the lifting devices in the DONES main building. After deciding the group of experts, the relevant criteria for assessing the lifting devices are proposed by experts and then through expert interviews, different weights should be assigned to all criteria. In the last step, all options will be evaluated based on each criterion. Their weighted sums are their final scores of optioneering. In the following paragraphs from 3.1 to 3.3, these steps are illustrated in detail.

3.1. Criteria definition

Seven groups of main criteria are defined by the experts regarding the lifting devices in two shipping bays. Each main criterion has several sub-criteria. Fig. 2 shows the hierarchy of main criteria and sub-criteria.

The explanation of the main criteria is included in Table 3.
All sub-criteria are explained below:

- Vibrations: How much vibration is inherent during operation and how much will it be translated into the lifted component, since there are very sensitive components to be transported
- Stability: How inherently stable is the device during operation, including sensitivity to instability induced by mishandling
- User Friendly: How easy operatable is the device for users
- Ease of Maintenance: How easy is the device to maintain
- Automation: How much of the device allows for automation

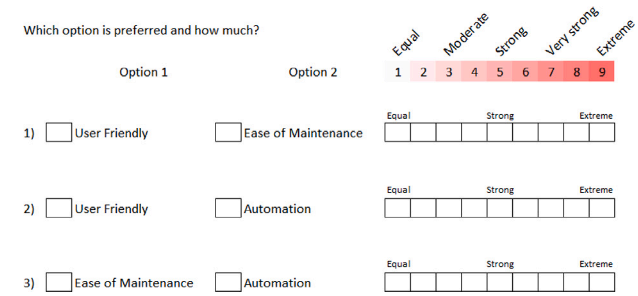

Fig. 3. The questionnaire for experts to identify the weights of sub-criteria under 'Ease of operation'.

Table 3
The description of main criteria.

Main criteria	Description
Dynamics	Includes the dynamic behavior of the lifting device
Ease of operation	How easy the device is to operate for users
Reliability	How reliable and robust is the device
Rescue/Recovery	Includes topics of rescue in case of a major failure
Operational time	Includes the total duration for operation
Cost	Includes the overall costs for installation and operation
Size	Includes the sizes and weight of the device

- MTBF: Mean-Time-Between-Failure
- MTTR: Mean-Time-To-Repair
- Recovery options: The possibility for a recovery in case of a major failure
- Recovery time: Time needed for recovery in case of a major failure
- Velocity: How fast the device allows transportation between floors
- Loading Time: How fast the device allows to load and unload from the bay (It is very important to reduce the downtime of the DONES facility. In the DONES project, it is planned to have 23days of maintenance every year [2]. During maintenance, a lot of components need to be transported by the shipping bays. The maintenance time is highly depended on the lifting velocity and loading time.)
- Upfront Cost: How much cost needs to be spent during construction
- Running Cost: How much cost needs to be spent during daily operation (including personnel cost)
- Size of supporting equipment: The dimensions of the supporting equipment
- Bay to Equipment Ratio: The ratio between the usable area in the bay and the reserved area for the equipment such as guiding rail
- Buffer size (Dimensions): How much space is left between the lifting device and the largest component transported
- Buffer size (Weight): How much weight allowance is left when transporting the heaviest load

3.2. Weights distribution

The weight of each sub-criterion is calculated with the help of expert interviews. The experts are asked to give their preference on every two sub-criteria. Fig. 3 shows an example of a questionnaire to identify the weights of sub-criteria under "Ease of operation". If one expert thinks that user friendly is extremely more important than ease of maintenance, he/she will choose user friendly in the first option and give a 9 to it for quantification.

Based on the answers from experts, their quantified preferences are calculated to get the weight of each sub-criterion. The weights will be shown in 3.3.

Table 4
The weights distribution and final evaluation of five possible lifting devices.

Criteria	Weights	Opt. 1	Opt. 2	Opt. 3	Opt. 4	Opt. 5
Vibrations	2%	4	4	1	3	3
Stability	5%	4	4	3	2	5
User friendly	3%	5	5	5	4	5
Ease of maintenance	1%	4	4	4	2	5
Automation	6%	5	5	4	2	5
MTBF	29%	5	5	3	2	5
MTTR	10%	4	4	2	1	4
Rescue options	15%	4	4	3	1	5
Rescue time	15%	4	4	4	3	5
Velocity	1%	5	5	4	3	5
Loading time	4%	4	4	4	4	4
Upfront cost	1%	5	5	3	1	5
Running cost	3%	4	4	3	2	5
Size of equipment	1%	4	3	3	1	5
Bay to machine ratio	1%	4	4	3	1	5
Buffer (dimensions)	1%	4	4	3	1	5
Buffer (weight)	2%	3	3	3	4	5
Sum		**4.38**	**4.37**	**3.19**	**2.07**	**4.82**

3.3. Evaluation

After getting the weights distribution, the five possible lifting devices are evaluated from 1 to 5 (very bad to very good) regarding each sub-criterion. The evaluation results are shown in Table 4. Options 1 to 5 are parallel ropes lift, heavy load storage and retrieval machine, rack and pinion lift, upside-down scissor lift and rigid chain lift respectively. It should be noted that the evaluation is based on the average values of each type of lifting device of the commercial products, since the customized lifting device for DONES main building is not yet in the engineering design phase.

4. Market research

According to the evaluation results in 3.3, parallel ropes lift, heavy load storage and retrieval machine and rigid chain lift are the top three evaluated lifting devices for the shipping bays in the DONES main building. In order to get an overview of the commercial products of these three types of lifting devices, market research is carried out and the results are dedicated in this section.

4.1. Parallel ropes lift

The requirements on the payload and stroke can be easily fulfilled by the commercial parallel ropes lift. There are numerous hoists suppliers which produce different payload hoists, such as *InnoKran* [3], *KULI Hebezeuge* [4], *Konecranes* [5], *Mammoet* [6]. The hoists can be installed in a machine room on the top of the building, four parallel ropes from the hoists will connect with a transport platform, and four guiding columns are then needed on the four corners in the shipping bays.

4.2. Heavy load storage and retrieval machine

Commercial storage and retrieval machines often have small load capacities, even the heavy load storage and retrieval machine has limited payload regarding the requirements in 2.2. For example, *MIAS* [8] has supplied storage and retrieval machines to customers all over the world since 1985. However, a 40-ton machine is still out of their scope. The product of *Dambach Lagersysteme* [9] has overall heights of up to 49 m with lifting capacities of up to 6000 kg. The *Mecalux* [10] has products with a maximum load of 1.2 t. The vertical lift module from *Kardex* [11] can only lift loads up to 1 t. Due to the limited payload of this type of lifting device, they will not be considered for further development.

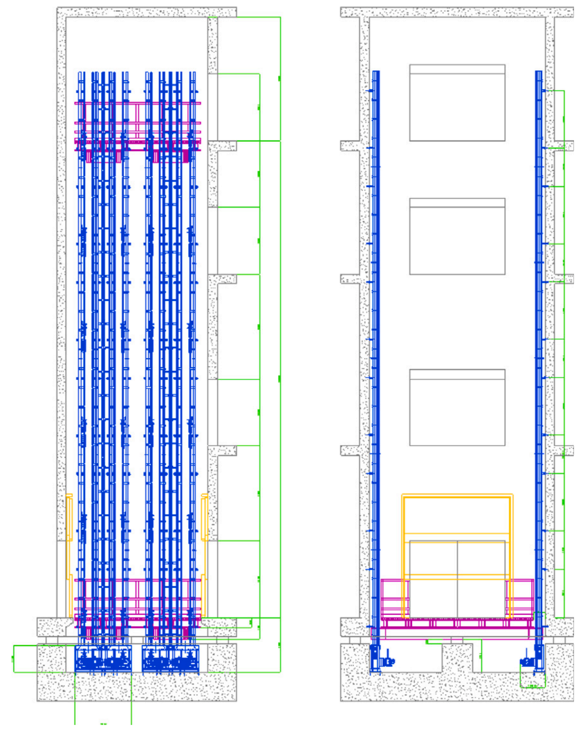

Fig. 4. The front view and side view of the rigid chain lift in the shipping bay [7].

4.3. Rigid chain lift

Most commercial rigid chain lifts are lifting tables combined with scissor lifts, whose strokes are very limited and cannot fulfill the requirements in 2.2. For example, the *Power-Lift* [12] is a UK supplier of rigid chain lifts and develops the "push chain technology" for heavy-duty scissor lift tables and lifting platforms, especially for the automotive industry. Their largest chain can only lift 3 tonnes up to 6 m. *Dynalserg* [13] is an enterprise in expansion in the fields of lifting, logistics, and maintenance. They have lifting tables with different types of power and mechanisms, e.g. scissor lift tables, and column lifts. However, the stroke and load capacity are limited.

To the authors' best knowledge, the only commercial rigid chain lift that can satisfy the requirements for both shipping bays is from *Serapid lift Systems* [7]. They develop and manufacture the original rigid chain and telescopic mechanical actuators for the horizontal and vertical movement of heavy loads for more than 45 years. In both shipping bays, they are able to install four linear chains in the shaft. A geared motor can be built directly on the chain for each drive train.

5. Principle sketches

In this section, principle sketches of rigid chain lift from *Serapid lift systems* are depicted and explained. It should be noticed that all sketches are for principle description, the dimensions may be modified in the future.

Fig. 4 shows the front view and side view of the rigid chain lift in the shipping bay. Four rigid chains are connected with the shaft walls, with two on each side. The connections are achieved by their special bolt system, which makes the vibration during loading/unloading within the limit of 2 mm. Since all chains will be stored on the side of the shaft, space reservation is needed for storing the chains. For each floor, two doors on both sides are planned for loading/unloading the components.

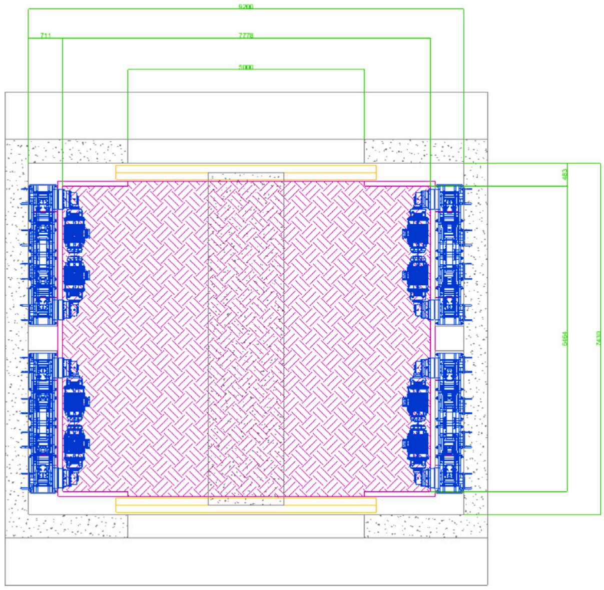

Fig. 5. The top view of the rigid chain lift in the shipping bay [7].

A transport platform, marked in pink, has a thickness of 1150 mm and is responsible for holding the components.

Fig. 5 is the top view of the rigid chain lift. For each rigid chain, a motor is planned as a driving system. The motors will be stored in the basement between the seismic pits.

6. Conclusion

In this paper, five possible lifting devices are proposed for the vertical transportation of components inside shipping bays in the DONES main building. Through optioneering the parallel ropes lift, heavy load storage and retrieval machine, and rigid chain lift outperform the scissor lift and rack and pinion lift. Market research is then carried out for these outperformed lifting devices. The research results show that commercial heavy load storage and retrieval machines cannot satisfy the predefined requirements for the lifting devices in the shipping bays. Thus, only the parallel ropes lift and rigid chain are further analyzed. At the end of this paper, the principle sketches of the rigid chain lift inside the shipping bay are provided to explain the installation and operation of the rigid chain lift. In the next step, the engineering design of lifting devices based on both options (parallel ropes lift and rigid chain lift) will begin taking the emergency (mechanical) stopper design into consideration. The shareholders will choose the most appropriate supplier of the lifting devices.

CRediT authorship contribution statement

Yan Wang: Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Martin Mittwollen:** Funding acquisition, Investigation, Methodology, Project administration, Supervision.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Martin Mittwollen reports financial support was provided by EUROfusion.

Data availability

Data will be made available on request.

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