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ABSTRACT

DEVELOPMENT OF INNOVATIVE, ALTERNATIVE RIGGING METHODS AND EQUIPMENT FOR SPECIALIZED HEAVY RIGGING INDUSTRY

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PREFACE

Modern technical progress uses more and more application and implementation of alternative modern and innovative solutions for the transportation, hoisting and lifting of heavy rigging loads.

Through this thesis the author capitalizes the experimental and theoretical results of seventeen years of specialized experience in the rigging, hoisting and transportation of heavy equipment.

The author is professional designer engineer, with significant experience in the field of heavy rigging, specialized in these fields and with designs in various industries and countries.

Alongside with his team made up of engineers, project managers, quality control engineers, industrial processors, operators and leaders, he ensured the successful completion of various transportation, hoisting and rigging projects for special heavy equipment, nuclear, metallurgical and energetic industry.

Besides his professional and engineering knowhow, combined with management skills, the author managed to bring a significant contribution to the complex engineering problems in rigging and transporting heavy machinery offering innovative and successful solutions regarding rigging industry, structural engineering, manufacturing, rigging and transportation.

NECESSITY AND IMPORTANCE OF RESEARCH

Transportation, hoisting and rigging systems for special heavy loads are complex systems of installation, with special structures, adapted and built depending on the requirements for rigging heavy special loads. These systems include a series of specifications, of heavy loads that require a series of precautions, first of all the operator' safety and the protection of the related equipment.

The approach and reasoning for developing alternative, innovative solutions for transportation, hoisting and mounting, take into consideration efficient risk management. Risk reduction or elimination for the staff as well as the environment and users are considered.

There are a series of incidents nowadays in the industry of transportation, hoisting and installation of heavy equipment, leading to loss of loads, installations damage and, more seriously loss of human life. This is the reason why creating alternative engineering solutions for transportation, hoisting and installations focusses on the safety and efficiency aspects.

A typical approach for the hoisting systems involve mainly cranes, with specialized mechanisms which already exists and must undergo modifications in order to conform to the requirements a typical project with a complex load and certain specifications, which belong to the category of special heavy loads.

The innovative approach developed in this thesis is illustrated by new solutions for the systems ensuring transportation, hoisting and mounting, so that they would meet the requirements for special heavy loads, as main objective, making possible the implementation of these solutions of modular systems as well, for future uses.

The solutions developed in this thesis are based on the requirements to which hoisting equipment are judged against, in view of verification of its technical condition, and automation. These verifications include the following stages:

- Verification of the main components transporting the load;
- Functional tests without the load;
- Load Tests, both static and dynamic;

- Other tests regarding the general components of the equipment.

The purpose of the doctoral thesis entitled "DEVELOPMENT OF INNOVATIVE, ALTERNATIVE RIGGING METHODS AND EQUIPMENT FOR SPECIALIZED HEAVY RIGGING INDUSTRY", developed by Bogdan Gaita engineer, is to present new solutions for the transportation, hoisting and installation systems intended for special heavy loads.

The achievements presented in the thesis reflect the results of the applied research and the experience acquired by the author in the implementation of various objectives included in the area of special heavy loads.

The objectives of the research refer to:

- Improvement of the existing transportation and hoisting systems;
- Ensuring safety in the Transportation, Hoisting and Mounting Systems (THMS);
- Ensuring environment and user safety;
- Risk reduction for the users;
- Cost reduction;
- Reduction of the time required for the tasks of transportation, hoisting and mounting for the special heavy loads.

RESEARCH METHODOLOGY AND RESULTS

The present stage of the THMS provides transportation, hoisting and installation functions for small and medium sized loads, without solutions for the oversized heavy special loads.

Rigging these large, oversized loads, such as modules in oil and nuclear industry, can be very difficult with the current means.

This doctoral thesis presents alternative solutions that are developed during research and structural design, considering the challenges related to the rigging of special heavy loads. As research methodology in this thesis the following were taken into consideration:

a. Presentation of current solutions used in the THMS;
b. Presentation and critical analysis of the THMS used at world levels for special heavy loads;
c. Case studies regarding THMS used by the PhD student regarding rigging of special heavy loads;
d. Developing personal original solutions, including in the form of an invention, for the THMS intended to the rigging of special heavy loads;

a. Thus, in Chapter 1, in a concise description, the current hoisting, continuous transportation installations are described, as well as terrestrial and suspended transportation installations, and THMS components for special heavy loads (flexible parts, winding and guiding devices, rolls, load suspension and fixing devices, braking and blocking devices, safety devices etc.).
b. In Chapter 2 the THMS characteristics are presented for special heavy loads, based on standards and general requirements on the design, the used materials, execution technologies, transport conditions.
   The critical study regarding the current THMS solutions underlines the necessity of their modification for special heavy loads. The necessity of reconfiguration is indicated for cranes, hydraulic cylinders and pumps, hoisting systems with shelves (pipes), means of transportation, modular systems etc.
c. Chapter 3 is dedicated to innovative solution, in the form of case studies, developed by the author, together with other specialists in the field, namely:

c1. A special system of beams for the installation of pre-cooling fans for plant equipment in a nuclear plant;

c2. Alternative complex solutions for hydraulic cranes and rolling bridges, solutions that will provide high capacities, safety and lower costs. Self-hoisting tower (more than 2500 t hoisting loads), Pipe Modular Lift System (PMLS), completely automated (with loads of up to 800 t), system with hydraulic cylinders, intended to lift structures of very high dimensions and weights (up to 6000 t), overhead bridge system for lifting and transporting special heavy loads of up to 60 t, Scorpion System used which attaches the support frame of the crane to the wall, without requiring permanent modifications or core drilling.

c3. Self-propelled modular transport (SPMT), with capacity for heavy loads, controlled by a wireless system with digital or analogous leading unit for transportation with a capacity of up to 180t per unit.

c4. Rigid chain technology, used to move special heavy loads for long distances;

c.5 Shark Link technology for lifting heavy loads, intended to function in combination with an overhead bridge or bridge with hydraulic legs (Hydraulic Gantry);

d. Chapter 4 is entirely original and explains the invention developed by the author, meant to develop the Pipe Modular Lift System (PMLS).

The invention entitled "*Apparatus, system and method for the modular hoisting system with pipes (PMLS)"* has in view a unique hoisting system for heavy loads, capable to transport very heavy loads from ground level to any elevation required for installation.

Chapter 4 presents the author's contribution for the application of invention principles for the design and calculation of the component elements of PMLS for special heavy loads, especially the application of this system in a nuclear installation.

CHAPTER 1

PLACE, ROLE AND STRM PARTICULARITIES FOR SPECIAL HEAVY LOADS

The transport, hoisting and mounting systems (THMS) have developed together with industrial development and modernization. Containerization, palletization, wrapping operations and extension of industrial fronts of loads discharge, continuous supply, semi-manufactured raw materials and modernization of transport resulted in increase of productivity.

The integrated production concept required constructive elements typically developed for the transportation equipment, structuring them on standard modules. These standardize modules are created to satisfy the requirement that should be effected in the transportation process. The transportation systems provide transfer, orientation, positioning and installation of loads all along the manufacturing process. The hoisting and transportation systems can be used for transportation of loads in limited dimension spaces or for long distance transportation.

CHAPTER 2

CRITICAL STUDY OF CURRENT TRANSPORT, HOISTING AND MOUNTING SYSTEMS (THMS) FOR SPECIAL HEAVY LOADS

THMS FOR SPECIAL HEAVY LOADS

From equipment presented in Chapter 1, in order to carry out the requirement of a heavy load project, those installations and equipment are used, which are adequate for special heavy loads.

Hoisting devices with hooks, which are developed in order to attach loads to cranes or to hoist and move loads from one place to another, are generally used to hoist and transport special heavy loads that are difficult to handle.

The hoisting devices used by THMS are regulated for instance by ASME BTH-1 Standard regarding their structure, taking into consideration the safety standard B30 (USA).

In the design of these hoisting devices used in THMS, the following general requirements are considered:

- Responsibility of the design: the hoisting devices should be designed under the direct supervision of a qualified person;
- Design criteria: all the hoisting devices should be designed for specified nominal loads, geometry, design category and service class;
- Methods of analysis: allowed tensions and tension intervals defined in ASME BTH – 1 [12]. The standard is based on the analysis of the resistance of classical materials, by the use of models, although another method of analysis might be used;
- Materials: the design requirement of ASME BTH – 1 [12] Standard are based on the use of carbon steel, steel alloy for high resistance constructions or thermally treatable alloys for constructions, mechanical and component elements. Similarly, other materials can be used, with the condition that the safety limits and resistance to fatigue should be equal to or higher than those in the Standard.
- Welding: all the welding drawings and procedures for steel fabrication, except those of adequate resistances or deemed as necessary, in the design of the welding, should be in accordance with the requirements of AWS D12.1/D14 [15], [26], especially when there is a conflict between AWS D14.1/D14.1 M and ASME BTH-1. BTH-1 Standard and its requirements will take precedence.

Temperature: the ASME BTH-1 Standard 12] design requirements will be taken into consideration, applicable when the temperature of the structural or mechanical component of the analyzed device (taken into consideration) is in the range of -4^0C and 66°C. (25°F up to 150 F). When the temperature of the structural or mechanical component is outside this range, an additional special design is made, based on specific conditions. The design requirements for the electrical components are considered applicable when the ambient temperatures do not exceed 104°F (40°C).

Design categories or methods:

The design categories defined below are established based on various design factors in the risk range that should be met in design. Nominal design factors are:

- 2,00 (at least) for the BTH hoisting devices of A category design
- 3,00 (at least) for BTH hoisting devices of B design category
- 6,00 (at least) for BTH hoisting devices of C design category

A design category

- A design category should be chosen when the range and variation of the loads applied to the BTH hoisting device are predictable, in case the loading and environment conditions are precisely defined or are not severe.

B design category

- B design category should be chosen when the range and variation of the loads applied to the BTH hoisting device are not predictable, in case the environmental and loading conditions are severe or are not precisely defined.

C design category

- C design category should be chosen to design hoisting with special applications.

CRITICAL STUDY OF CURRENT SOLUTIONS

The THMS solutions presented in Chapter 1 specify the functions that might be supplied, namely transportation, hoisting and installation, but their general use is for normal loads.

There are various systems and methods currently used to transport heavy loads vertically. There are various problems with the current methods, in case the hoisting methods require all the loads being suspended, conventional attachment methods for the unit mounted (for example belts, cables), called henceforth "conventional hoisting methods", all present inherent failure risks. Many of these conventional hoisting methods use cranes, which require time consuming preparations, prone to human failure, unsafe services due to wind speed and programing difficulties.

The construction and operation of these installations and devices for the implementation of THMS should be reanalyzed for special heavy loads.

Thus, hydraulic cylinders are limited by the weight of the general load. Therefore, these should be reconfigured for positioning the hoist of the special heavy load. Similarly, the cranes of over 100 ton should be structurally reconfigured to meet the new hoisting requirements. The means of transportation have been modified to provide the transportation of oversized heavy loads. The modifications involved a series of modifications by supplementing the number of trailers and modification of the travel system.

Structural modification of the design also took in account modularization. This characteristic, modularization allowed THMS devices and installations to be flexible and to be able to be adapted with minimal costs to the given conditions.

CHAPTER 3

CASE STUDY

ALTERNATIVE AND COMPLEX METHODS APPLIED TO THMS FOR SPECIAL HEAVY LOADS.

Alternative and complex methods applied are alternative solutions for cranes and hydraulic gantries in accordance with a new approach for specialized hoisting systems and hardware equipment. The rigging solutions ensure more flexibility and are modularly built and designed with the dimensioning and verification of the basic component of the unit. The proposed systems have a higher capacity of hoisting and are safe, economical for installation and implementation and meet the regulations regarding risk management.

Case study 1: Self-hoisting tower (ESET) is configured for the hoisting of the loads in the range of 1000 ton and 2500 ton, which will be lifted up to 100 m.

The solution presented does not require any cables. The system is delivered in containers and configured on sliding runways.

Case study 2: Another alternative innovative system is the Pipe Modular Lift System *(PMLS).* This system has two assembly variants:

PMLS variants have hoisting capacities of 400, 800, 1200 and 1800 ton and mechanically lift and lower the load. The system is computerized and synchronized electronically. The hoisting speed is 0,508 m/min, vertical travel distance is up to 60,69 m, and the clearance inside the deck is 15,24 m or more.

PMLS solution can have square, rectangular or round basis, the platform is designed in such a way as to accept SPMTs or any other material rigging equipment. The lifting mechanism is always mechanically engaged ensuring the safety or the load and personnel. Also, the whole PMLs can be assembled in 3 to 4 shifts. The wind was considered, and operations are safe up to 90 km/hour and with a lateral load limit of 5%. Twelve trailers are used for standard configuration transport.

Case study 3: H*oisting system (JS line)* is the completely automatic and monitored alternative solution used to hoist the base of the frame and of the steel boxes named barrels. Hoisting capacity varies in the range of ton 125 and 800 per hoisting unit, jacking speed being up to 6 meters per hour. The starting height is from 6 meters, and the maximum height is more than 80 meter.

The system is completely automatic. Depending on the model, it can be loaded with 3-5 % lateral load. Standard containers *are* used for transport.

Case study 4: Mega Jack-system is an innovative solution designed to hoist very large heavy structures.

Mega Jack system has a capacity of 5200 ton per tower and uses several towers that work simultaneously. The system is monitored by computers. The 12 tower system offers a load lift capacity of 60000 tons.

The basic standard dimension is approximately 4 m per 4 m. Each tower has 4 powerful platforms. In each platform (seat) there is a 13000 ton hydraulic system. Hydraulic cylinders have a 49 cm stroke. The beams are automatically introduced with the help of an integral rolling system

Travel Gantry System, which is transport and hoisting system that increases safety and efficiency of transportation for special heavy loads. It extends from the container size to a footprint of 32 m long and 16 m high. The maximum work load is up to ton 60. This hoists the load up to 26 m high. The travel speed is 2,5 km/h.

The solution is developed and operates with autonomous hydraulics, telescopic and Diesel actuated cylinders. The travel in the desired direction is normal, crab or carousel. This system is flexible and its installation is automatic in less than one hour.

CHAPTER 4

NEW IDEAS AND SOLUTIONS FOR THMS DEVELOPMENT

INNOVATIVE SOLUTIONS, ALTERNATIVE DEVELOPMENT OF THMSs, STARTING FROM THE PARTICULARITIES OF DEFINING SPECIAL HEAVY LOADS

Particularities defining special heavy loads determine finding solutions that would allow transportation of oversized loads, then installation of those with special hoisting installations/mounting them in the desired locations.

In this thesis, new solutions are developed allowing creation of transportation, hoisting and mounting units that use modular systems. These modular systems allow short-term development of equipment required at the premises of the beneficiary, with low costs. The principal contribution of the author is

designing and patenting a PMLS (Pipe Modular Lift System), a system that has been proved feasible for numerous industrial applications that require transport, hoisting and mounting of special, heavy loads. Modular systems can be prepared before the contract is executed and are delivered in containers, the rest of the equipment being mounted and positioned by the client.

Modular systems are made up of beams of various dimensions, depending on the type of the load. These are dimensioned and verified based on existing standards that define the procedures for their execution. What is important for dimensioning and verification is ensuring the safety coefficient required specified in the design norms, providing the safety of the personnel and equipment.

Installation of the modular system involves a series of assembling procedures, such as welding and assembling with structural bolts. For these procedures a series of dimensioning calculations have been made in the thesis and a series of welding procedures have been developed, and for the assembling with special structural bolts and heavy nuts, special construction screws have been designed, to provide tightening and completion for handling special heavy loads.

New concepts of special flanges and nuts have been presented in the thesis, which will secure the support platform of the PMLS system. All these have been analyzed, dimensioned and verified, according to US Standards. New solutions have been proposed regarding development of the modular construction using actuation with the help of very high powered electric motors, capable to hoist and move the special heavy load.

Another innovative idea presented in the paper refers to the hoisting of the load with the help of a platform. The transportation of the load is made with special transport equipment (SPMT), ensuring – through their design - a uniform distribution of the weight on the wheels, and in the case of certain transporters, the wheels pivot around an axis, modifying the travel direction of the load.

It has been specified in the thesis that in the case of an oversized transportation, the length of the load most frequently requires several transportation platforms (trailers), which are carried by only one heavy weight motor.

The problem of handling special heavy loads has been studied and solved by the use of specially designed platforms. The dimensioning calculations and verification comply with US standards.

The dimensioning calculations and verifications for the equipment used for the PMLS are supplemented by calculations that take into consideration the environmental conditions, such as wind speed, seismic activity etc. these being specific to the place where the project is implemented.

“APPARATUS, SYSTEM AND METHOD FOR THE MODULAR SYSTEM OF HOISTING WITH PIPES” (PMLS) INVENTION

One of the main contributions of the author of the thesis to the modernization of the modular systems of hoisting with columns for heavy loads lies in the development and patenting of an invention with the title *“Apparatus, system and method for the modular system of hoisting with pipes*”. The patent, together with the details of the drawing of the constructive parts of the modular system, is shown in Annex 1.

BACKGROUND OF THE INVENTION

There are various types of apparatus, methods and systems used presently to transport heavy loads vertically. There are several issues with the present methods, in the sense that the current hoisting systems require suspended loads, conventional methods of rigging (for example, belts, cables), called henceforth “conventional hoisting methods”, all these being able to lead to failure. Many of these conventional methods use cranes, necessitating time consuming preparations, and are prone to failure due to maneuvering, unsafe services due to wind speed and planning difficulties.

INVENTION SUMMARY

The vision for this invention is a unique hoisting system that would be capable of transporting very heavy loads from ground level to any elevation required by the project. While the invention is developed in many different forms, the present configuration is described in drawings and the preferred configurations of this invention will be described in detail. (Annex 1, Fig. 1 – A, item 50) is a motor driven gearbox the gears of which are paired with a long threaded rod (Annex 1, Fig, 1 – a, item 40). Two motors (Annex 1, Fig. 1 item 70) rotate the shafts supplying the gears of the jack with the screw of the machine (Fig. 1-1, item 50), which determines in its turn the rotation of the threaded rod. The platform is fixed to this threaded rod by a set of nuts, which travel on the pipe. The rotation of the threaded rod determines the travel nut (Annex 1m Fig. 1 – B, item 10) to move vertically, lifting the platform (Annex 1, Fig. 1 item 110). The load is transferred from the platform to the travel nut by the threaded rods (Annex 1, Fig. 1 - A, item 200), which moves through the machine by a jack screw gear in the pipe columns.

ADVANTAGES OF THE PATENT

The advantages of this system compared to the conventional hoisting methods are numerous and only a few will be presented below:

- Considering that the threaded rods keep a firm contact with the travel nut, there is a continuous steel – steel contact at any moment in which the load is lifted. The safety factors for the threaded rods failure by shear are greater by far than the safety factors usually found when conventional hoisting methods are used.
- Inherent risks of rigging and cranes are eliminated by the use of PMLS.
- Meetings before rigging activities, preparations for hoisting, surveillance of rigging and various other requirements inherent to conventional hoisting methods are eliminated.

PMLS CONFIGURATION

Configuration of the PMLS that will be installed at the nuclear plant reflects the standard PMLS configuration for the SPMT transporter. Also included are the ground bearing pressures at each contact point of the system. Interface loads included in this document are limited to loads at ground level (altitude 609,6 m).

Standard configuration allows transport with SPMT from ground level to a height of approximately 15, 24 meters over the ground.

Standard configuration means four (4) pipe columns that support a machine actuating device with threaded rod at each column. At the base of each column, a column pedestal distributes column loads to the support surface at ground level.

Each travel nut supports a travel nut bracket connected to a lift beam spanning the long direction of the system [see Annex 7]. The lift beam supports the array of deck section panels, which span the short direction of the system. The deck will consist of seven standard deck panels, on transition deck panel, between the standard deck panel array and the PMLS to Hatch Bridge Platform, and one transition deck beam between the deck panel array and the ground load ramp. [35].

The Enerpac synchronized actuator system is made up of four actuators with screws of the M150 machine, twelve 5, 4864 m sections of acme threaded rods, four travel nuts, two gear reducers, and two motors, as well as miscellaneous coupling, electrical and cooling system components.

The PMLS System will require two 480 VAC, 100 A, as supply source close to the base of the system.

The functioning cycle of the system is limited by the heat generated in the gears with threaded rod and travel nut, which should be kept low enough so that the components resistance and durability would not decrease. The screw jack manufacturer has determined limits for the operating temperature of the travel nut at the installed thermocouples and for screw jack housing lubrication oil temperature. If these two temperatures are kept within admissible levels, the system will be able to operate continuously.

Existing structures [31] [Annex 5]:

PMLS is designed in such a way as to lift the deck to a height where the load will be transported to a transition deck, which is supported by the existing exterior equipment. The transition ramp will rest on a beam spanning the PMLS columns that are the closest to the platform. The ramp will not be positively connected to the PMLS and will only bear on the column support beam. Consequently, any lateral loads and/or movements imposed on PMLS would not be transferred to the transition ramp and to the existing platform. (Annex 5).

CHAPTER 5

CONCLUSIONS. ORIGINAL CONTRIBUTIONS.

The paper proposes innovative, alternative and original solutions for the systems ensuring transportation, lifting and installation of special heavy loads. These have been developed as a requirement for these specific industries, all the presented ideas being implemented afterwards in various specific systems in the economic environment.

Approaching this subject is justified by the fact that the apparatus, methods and systems used so far for the transportation, lifting and installation of special heavy loads show various weaknesses, leading to failure, they are time consuming, provide unsafe service, planning difficulties, etc.

A first contribution of the author refers to the synthetic selection of complex alternative methods applied to STRM, for special heavy loads, such as the self-lifting tower (lifting loads of 2500 t), modular lifting system with columns (PMLS), completely automated trolleys (up to 800 t), the hoisting system with large cylinders, intended to hoist structures of very heavy and large sizes (up to 60000), Travel Gantry hoisting and transportation system for special heavy loads up to 60 t, Scorpion System, rigid chain technology and Shark Link heavy hoisting system.

Another case study refers to the project of replacing the Feedwater heater in a nuclear plant.

The developed solutions proposed in the thesis ensure transportation, hoisting and installation, complying with the requirements for special heavy loads, making their implementation possible as modular systems for future applications uses.

The author considered the advantages of the innovative solutions proposed, considering the following aspects:

- Safety is paramount starting with the design of the lift systems;
- They are an alternative to the conventional solutions for cranes and hydraulic gantries;
- They represent a new approach for the specialized systems of lifting special heavy loads;
- They are solution of installation with flexibility in mind, built in a modular approach;
- Cost optimization, by improving safety, installation and implementation conditions;
- The research objectives developed in the thesis also consider ensuring environment protection, reducing transport time, lifting and installation of special heavy loads.

A variant of this invention is a unique system of hoisting, capable to transport very heavy loads at heights required by the project. Considering that the invention is ready to be deployed in several variants, they are presented in drawings and are described in detail in the paper.

I have identified a series of advantages of the patented solutions compared to the conventional methods, such as:

- Since the threaded rod keeps a firm contact with the travel nut, there is continuous steel-steel contact in any moment in which the load is transported. Safety factors in the case of thread damage due to shear are larger than the safety factors usually found with conventional lifting methods.
- Human error risks and consequences are lower than with a crane and installation operator;
- Meeting preceding lifting, which are very time consuming, preparations for the lifting planning, mounting acquisition and surveillance and requirements inherent to conventional hoisting methods, are eliminated;

The thesis also presents new special flanges and travel nut concepts connecting the PMLS support system. All these have been analyzed, dimensioned and verified in accordance with US Standards. The new solutions proposed for the development of modular systems use powerful electric motors, capable to hoist and move special heavy loads.

Another innovative idea refers to hoisting the loads with the help of a platform, The transportation of the load is done with special transport equipment ensuring by their construction an even distribution of the weight on the transport wheels, and in the case of certain transporters, the wheels pivot around the axes and modify the travel direction of the load.

It should be emphasized that all these ideas have novelty character and are the result of needs from specific industries working with special heavy loads, necessitating imminent solutions to these problems.

Other important original significant contributions refer to the design drawings and calculations of the PMLS component elements for special heavy loads.

The calculations made are rigorous from mathematical point of view and have been performed with dedicated numerical calculation programs, and the drawings of the of the component elements comply with the prescriptions of specific Standards, correlated with the requirements of the beneficiaries, these being at the basis of the design, conception and implementation of the presented configurations.

In conclusion, the innovative solutions proposed in the thesis, developed by design and analysis, have been implemented in the specific industrial applications in the field of heavy loads.