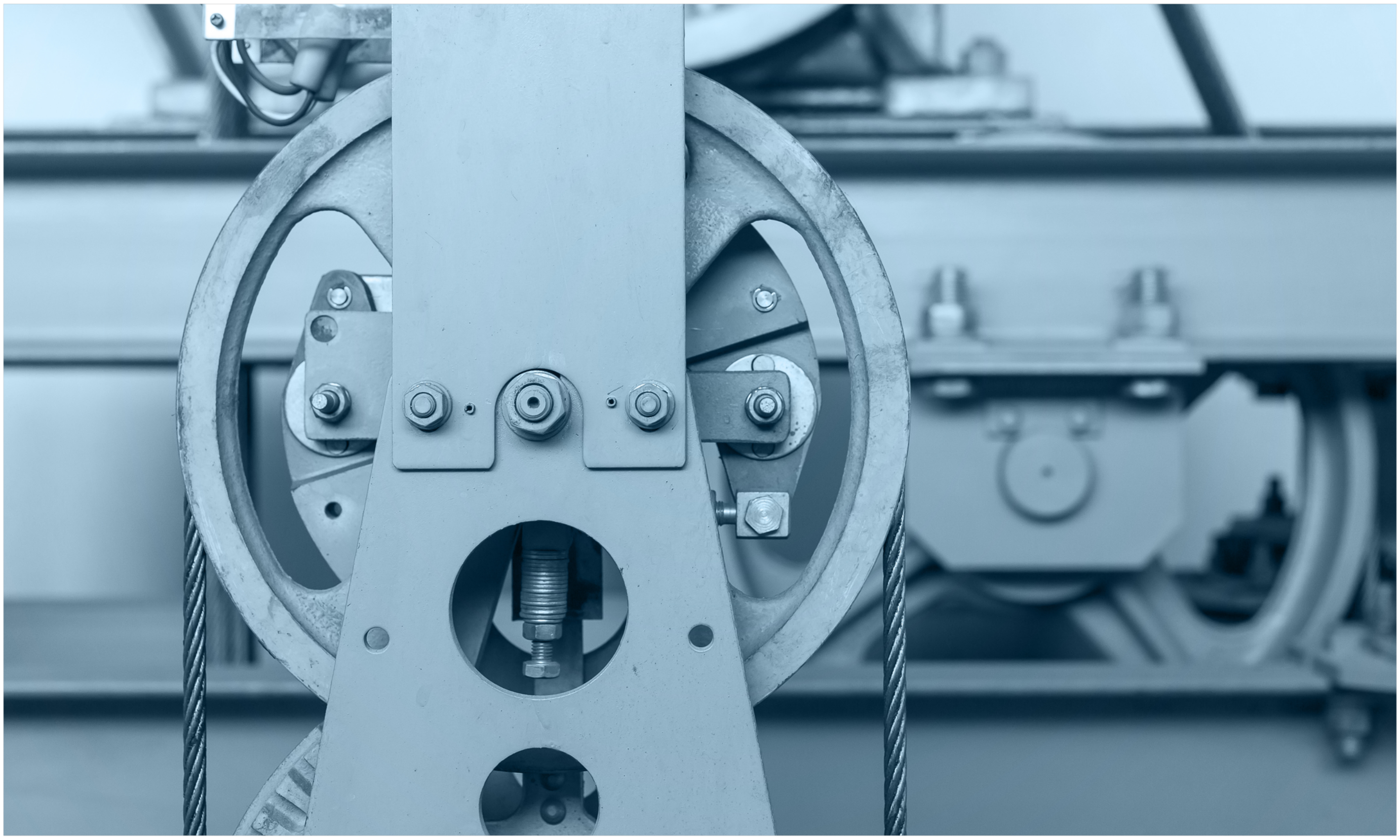
Hoist winch gearboxes and brakes on STS cranes

A PEMA Information Paper



This information paper provides commentary and practical guidance following the trend of increasing container ship sizes and what affect the need for larger Ship to Shore cranes is having on hoisting height and outreach.

PORT EQUIPMENT MANUFACTURERS ASSOCIATION

Equipment Design & Infrastructure Committee
Workgroup 'Mechanical Components'
Hoist winch gearboxes and brakes

Revision	1.6	02-10-2019
Distribution	P. Bellinghausen	Sibre
	U. Dröge	SEW-EURODRIVE GmbH & Co KG
	G. Fischer	Siemens
	S. Hoite	Liftech Consultants Inc.
	P. Karaivanov	PEMA
	C.M. Langeveld	Langeveld Project Management B.V.
	C. Lautwein	M.A.T. Malmedie Antriebstechnik GmbH
	K. Rintanen	Konecranes
	C. Römer	Römer Fördertechnik GmbH
	M. Scheidt	Sibre
	U. Wurster	EMG Automation GmbH

PORT EQUIPMENT MANUFACTURERS ASSOCIATION

CONTENTS

1. INTRODUCTION

Following the trend of increasing container ship sizes, container terminals face the need for larger Ship to Shore cranes with respect to hoisting height and outreach. In order to maintain high productivity, operating speeds of trolley traveling and hoisting are increased by installing more motor power.

As a consequence, motor dimensions also grow with higher rotating masses (inertia) as a result. The action of sudden stops of this type of heavy duty and high speed winches may cause gearbox damages such as bearing damages, gear tooth damages (pitting) or leakage.

Although both hoist gearboxes as well as hoist brakes are described by the general international crane standards, there seems to be little connection between the two. Gearboxes are usually specified in terms of their fatigue life time and potential overload situations, but often without taking into account the dynamic effects during sudden stops.

This PEMA-paper aims to:

a. Provide a clear problem description of the root cause of the gearbox damages
b. Illustrate the root cause of the gearbox damages by presenting examples of common specifications
c. Provide an overview of types of sudden stops
d. Provide a first inventory of the available gearbox protection principles currently on the market
e. Illustrate a basic insight in the physical brake sequence
f. Provide a summary feedback from crane end users on this type of gearbox damage
g. Provide overview of general gearbox failure causes

2. PROBLEM DESCRIPTION

Most modern container cranes are equipped with a double braking system on their hoist winch. Reference is made to Figure 1 for a typical example of this winch type with a double brake system:

A. Fast working emergency brakes on the hoist drum (reaction time e.g. up to 200 ms)
B. Somewhat slower working service brakes on the motor shaft (reaction time e.g. up to 450 ms)

In case of a 'sudden stop', this leads to the situation where the complete winch is braked by the emergency brakes until the contribution of the service brakes is started. During this period (approx. 250 ms in the presented example), the total high speed inertia is braked through the gearbox by the emergency brakes on the low speed side of the winch.

The root cause of the gearbox problems is principally approached from two different angles:

i. The view that the large rotating inertia of the high speed side (motors, couplings, disc brakes) forms the root cause of gearbox damage Reduction of inertia is recommended.

ii. A second view is that the induced brake torque and the different timing of the brake torque application forms the root cause: fast and synchronous braking systems are recommended from this view point.

In any case, all too often, the described situation leads to a condition that is normally not specified for the gearbox and results in gearbox damage. This is illustrated in the next two chapters, where examples of common specifications for hoist gearboxes and brakes are presented.

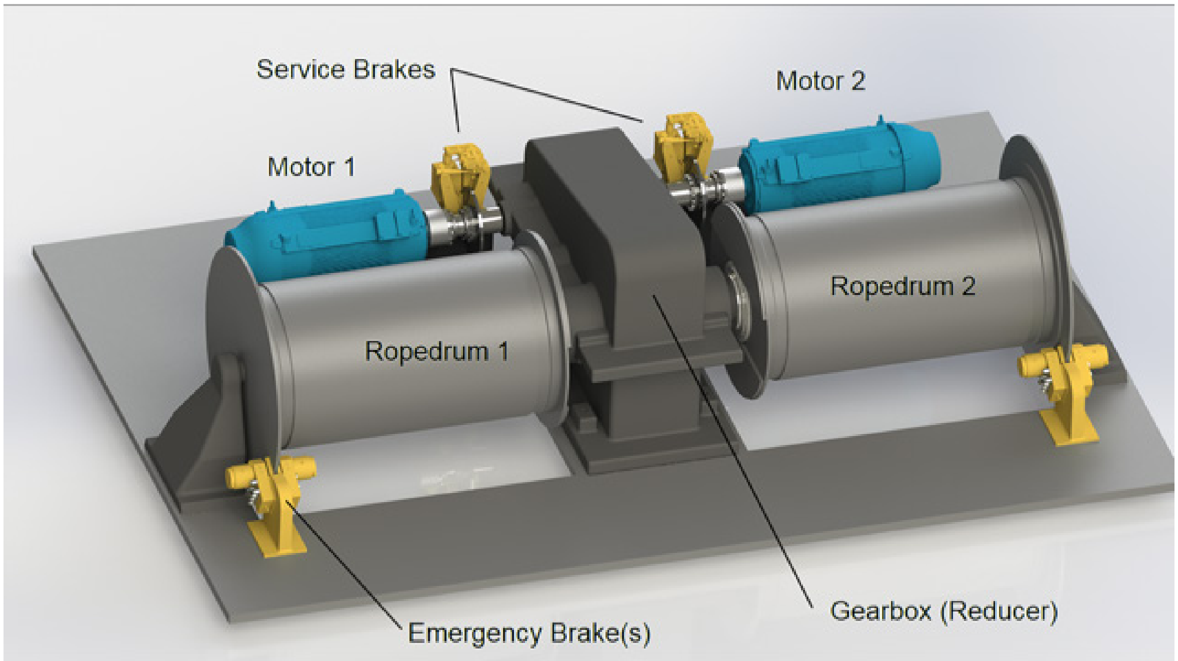


Figure 1 Typical hoist winch set-up STS crane (courtesy M.A.T. Malmedie)

3. FIELD EXAMPLES OF TYPICAL GEARBOX AND BRAKE SPECIFICATIONS

This chapter presents anonymous examples from actual specifications, originating from both end users (terminal operators), as well as consulting companies.

3.1 Comparison of "typical" main hoist brake specifications

Terminal Operator "A"

Each main hoist service disk brake stops rated load within 2.5 meters (w/o emergency drum brakes. Main hoist drum brakes stop rated load within 2.0 meters (w/o service disc brakes).

Terminal Operator "B"

Two thruster operated calliper disc brakes shall be provided (sizing and number of brakes to be demonstrated in calculations). Each brake shall have a dynamic rating equal to at least 100% of the torque required when main hoisting the rated load at the shaft where the brake is mounted. The combined braking torque – of main hoist motor brakes – shall be sufficient to stop a rated load lowering at rated speed under emergency stop conditions within a distance of s=v/50 [m] (= 1.8 meters).

The combined braking torque of drum brakes shall be sufficient to stop a rated load lowering at rated speed under emergency stop conditions within a distance of s=v/25 [m] (= 3.6 meters).

Terminal Operator "C"

Each brake or set of service brakes mounted on one side of the reducer shall be able to stop and hold the rated load from the rated speeds within 1.5 meters (w/o emergency drum brakes).

Stopping distance for the complete set of emergency brakes mounted on the drums, under emergency stop conditions, shall be not more than 2.0 meters (w/o service disc brakes).

Consultant:

As a minimum, there shall be two main hoist motor (service) brakes, with each individual brake having torque rating no less than 100% of the torque required to raise full rated load at rated speed. There shall be at least two main hoist drum (emergency) disc brakes, with a combined torque rating of no less than 175% of the maximum torque required to raise the load.

3.2 Comparison of "typical" Main Hoist Gearbox (reducer) specifications

Terminal Operator "D"

A calculation of helical gears and pinion shafts: Calculation is according to ISO 6336.

Tooth bending strength sFlim = 500Mpa. Safety factor SF = 1,40. For tooth root strength specific stress concentration factors considering actual geometry can be applied.

Terminal Operator "E"

Design, installations and material for gears and gearboxes shall comply with ISO standards and shall be state of the art. Gears and bearings shall be capable of absorbing overloads due to either the motor stall torque load without incurring plastic deformation of the gear teeth or the rolling elements or the raceways of the bearings.

Terminal Operator "F"

Gear reducers shall be designed and rated in accordance with FEM 1.001 and DIN 3990 or ISO 6336, but with a minimum service factor of 1,60 Manufactured gear reducers for the main hoist, boom hoist, shall be selected by multiplying the nameplate kW rating of the designed driving motor by this service factor in order to obtain the equivalent nominal mechanical rating.

Consultant:

Main hoist, trolley, boom hoist, and gantry gearing, including gear strength and stress, shall be designed and rated in accordance with the latest applicable standards issued by ISO 6336 (SFS 4790) and AGMA and design loads as per FEM 1.001 latest edition. Allowable stresses at FEM combined operating loads will be per AGMA with service factors for the main hoist durability: 1,5 and for bending: 2.25.

3.3 Conclusion comparison of specifications

As seen in sections 3.1 and 3.2, in many practical cases hoist gearboxes and hoist brakes are specified completely separately from each other. Apart from this, a variety of different specification types is observed.

In many cases, exceptional loads resulting from the emergency brakes due to snag load and sudden stops are not mentioned at all in the specifications. As a result, gear unit manufacturers are often in the dark regarding the real loads that will be applied to the gearboxes. This results in the situation where the gear unit manufacturer can only assume the real loads based on his experience.

Terminal operators often have a different understanding of what is happening in the application compared to the crane manufacturer. In most cases, the crane manufacturer is the party who specifies the gearboxes to the gear unit manufacturer, the brake manufacturer, and so on. As a result, these specifications may not accurately reflect the intentions and use of the terminal operator. For this reason, clear communication and involvement of the involved parties (the OEM, the end user and the gear unit manufacturer) is recommended.

4. DEFINITION OF SUDDEN STOPS

In order to take a closer look on the potential scenario's on Ship to Shore cranes, the following type of sudden stops are identified.

4.1 Category 0 Emergency stop

The power supply is cut-off, the crane reacts with a mechanical emergency stop since electrical braking is no longer possible.

4.2 Category 1 Emergency stop

An emergency stop is induced by one of the crane control functions. The trolley traveling (and gantry) motion and the hoist movement is brought to a controlled fast stop.

4.3 Snag load

The container or empty spreader is stuck in a ship's cell while being hoisted, causing an immediate stop of its vertical motion. After detection by the overload system of the crane, an immediate emergency stop is activated in order to bring the hoist winch to a full stop as soon as possible.

Often a high number of failure modes concerning different events (sometimes >100) are programmed in the control system which result in the activation of the emergency brakes in case of such events. Therefore, it could be that the emergency brakes are activated very often with the consequence that the frequency of occurrence of such exceptional loads also results in gear unit damages after a certain time. Such events should be analysed to see if it is really necessary to activate the emergency brake. As the name implies, it is about a brake which should only be activated in the event of real emergencies and not for any other events which could be solved by electrical braking or braking with the service brake for example.

5. GEARBOX PROTECTION PRINCIPLES

Currently, a total of four different physical principles are found on the market to protect gearbox overload:

5.1 Reduction or decoupling of rotating inertia
5.2 Fast and synchronous working brake systems
5.3 Snag load prevention by early detection
5.4 Hydraulic release systems (not represented in workgroup at present)

Table 1 presents the benefits of each of the four physical principles per sudden stop type.

Situation	Inertia reduction	Fast/synchronous brake system	Early detection	Hydraulic systems
E-stop up	X	X		
E-stop down	X	X		
Snag load	X	X	X	X

Table 1 Benefits gearbox protection principle per sudden stop type

6. BRAKE SEQUENCE CALCULATION

In order to obtain insight in the physical brake sequence, a calculation or simulation model can be advantageous, e.g. in answering a number of questions, such as:

1. What really happens in the ca. 500 ms during the braking sequence?
2. How do brake torque, motor inertia and gearbox torque interfere?
3. What is the influence of tolerances in the gearbox and the couplings?
4. What is the influence of the torsional stiffness of components (e.g. the gear unit), stiffness of the crane steel structure, steel base frames and damping elements in the system?
5. What is the impact of any proposed solution?

The advantage of a physical calculation model is that the hoist winch is regarded as a dynamical system instead of individual components. A typical example of what the output of such a calculation model might look like is presented in Figure 2.

Typical input parameters and approaches of such a calculation model are:

- Is motor counter torque considered or not?
- Static or dynamic gearbox model
- Hoist rope length (machinery or rope trolley)
- A re the tolerences of the gearbox and the couplings modelled or not?

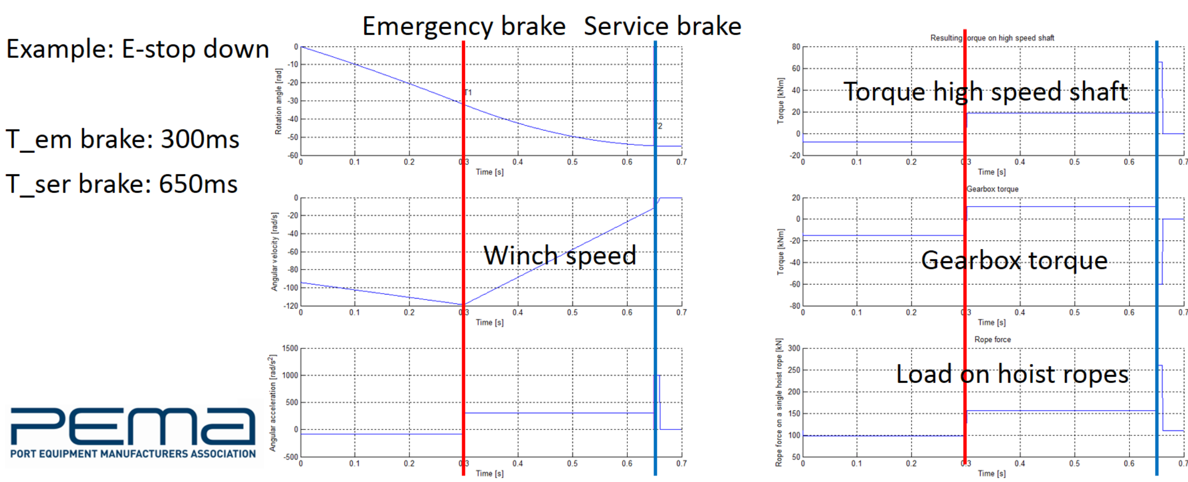


Figure 2 Example of typical calculation of a hoist winch braking sequence

Furthermore, a number of physical parameters play a dominant role in the braking process:

- Friction coefficient, depending on the brake temperature
- Thruster properties, such as response time
- Tolerence in the gearbox, couplings and brake mechanism
- Rotating inertia and inertia of the brake mechanism

Fast acting brakes on the high speed shaft will have positive effects, but there are different scenarios in braking. In some of the scenarios, fast brakes will also have negative effects.

For example, during E-stops in hoisting motion, if the high speed brakes stop first, it might cause a tooth flange change in the gearbox which will possibly result in damages. In worst case scenario the fast brakes have stopped the drive before the container stops moving upwards, this causes slack rope and subsequently a big shock load. State of the art brake systems have different response times depending on different situations.

Apart from the reaction time of the brake release unit, other parameters influencing the braking time are:

- Efficiency of the mechanical brake linkage (e.g. spring preload)
- Time needed to build up the friction coefficient between brake disc and brake lining
- State of maintenance of the brakes

7. GENERAL GEARBOX FAILURE MECHANISMS

Although this PEMA publication has focussed on gearbox damage in hoist winches of STS cranes during sudden stops, it is worthwhile including a list of general gearbox failure issues on cranes.

Common root causes of gearbox damages on container cranes are:

1. Uneven gearbox foundation, causing stress in the housing.
2. Lubrication problems:
   a. Splash lubricated gearboxes with difficult geometries, resulting in poorly lubricated bearings and teeth.
   b. Highly loaded gearboxes needing additives in the oil.
   c. Heating of the gearbox oil, damaging the lubricating function of the oil.
   d. Large speed differences in the stages of the gearbox, resulting in the need for different oil viscosities at the low speed and high speed sides.
   e. Large differences in ambient temperature, resulting in the need for different oil viscosities during winter and summer.
3. Application of relatively light weight gearboxes, resulting in smaller shaft distances. This may lead to very little material between the bearing houses.
4. Usage of poor gear materials and low quality bearings.
5. Poor adjustment of the axial bearing clearance of the shafts.
6. Peak loads during sudden stops, as described in this paper.

A list of common symptoms as a result of the above described root causes are:

A. Gear teeth damages (pitting, breaking teeth).

B. Bearing damages, resulting from:
   - Poor lubrication
   - Poor bearing quality
   - Axial hammering of intermediate gearbox shafts
   - Radial bearing overloading

C. For application of light weight gearboxes with little housing material between the bearings: shifting of the upper housing relative to the lower housing, forcing the outer bearing rings into an oval shape and thus hindering the barrel movement.

D. Damage to Keyways including shaft fracture.

8. FEEDBACK OF END USERS STS CRANES

In order to obtain an insight into the degree to which end users of STS cranes suffer from the described type of gearbox damage in real life, PEMA has conducted a market research among 10 container terminal operators, owners of a total of 171 STS cranes. Figure 3 shows the geographical location of the participating terminals, which are further kept anonymous in this report.

Figure 4 shows the average number of E-stops per STS crane per month per end user. As seen in this figure, there is a large variation in E-stops among the end users in practice. It should be noted that this can be caused by a number of reasons, such as operation type, power supply quality, etc.

Figure 5 shows the average amount of gearbox damage per STS crane per month by type: gantry traveling, trolley traveling, main hoist and boom hoist. As seen in this figure, some terminals experience significant gearbox problems in crane movements other than hoisting, which is further illustrated in Figure 6, where the average gearbox damage per 1000 operating hours are displayed.

Finally, figure 7 presents the root causes of the gearbox damage as reported by the end users.

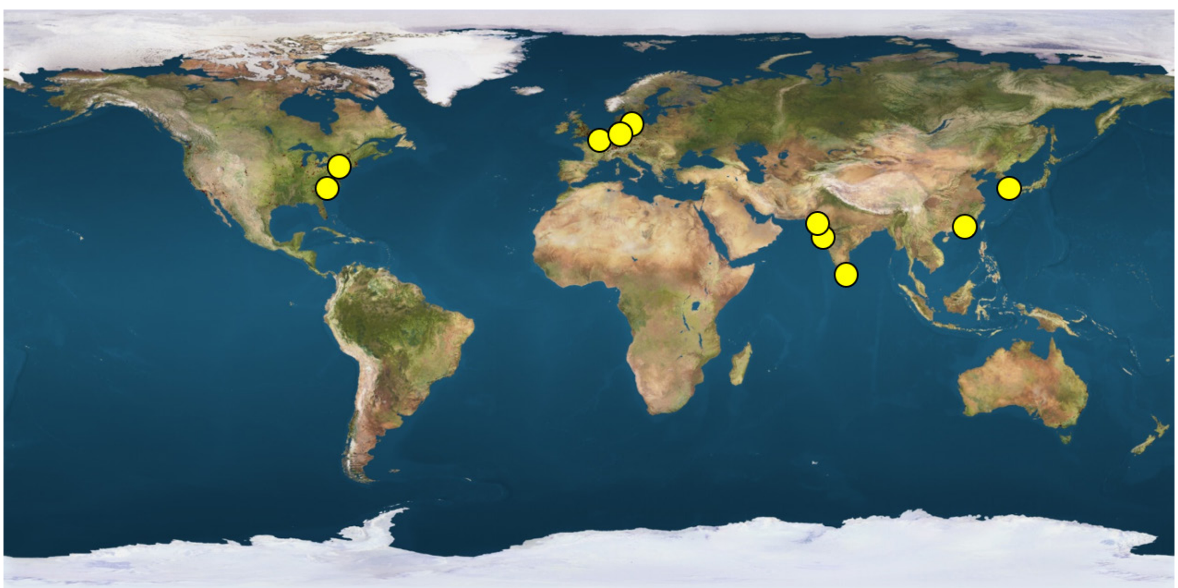


Figure 3 Geographical location participants PEMA market research

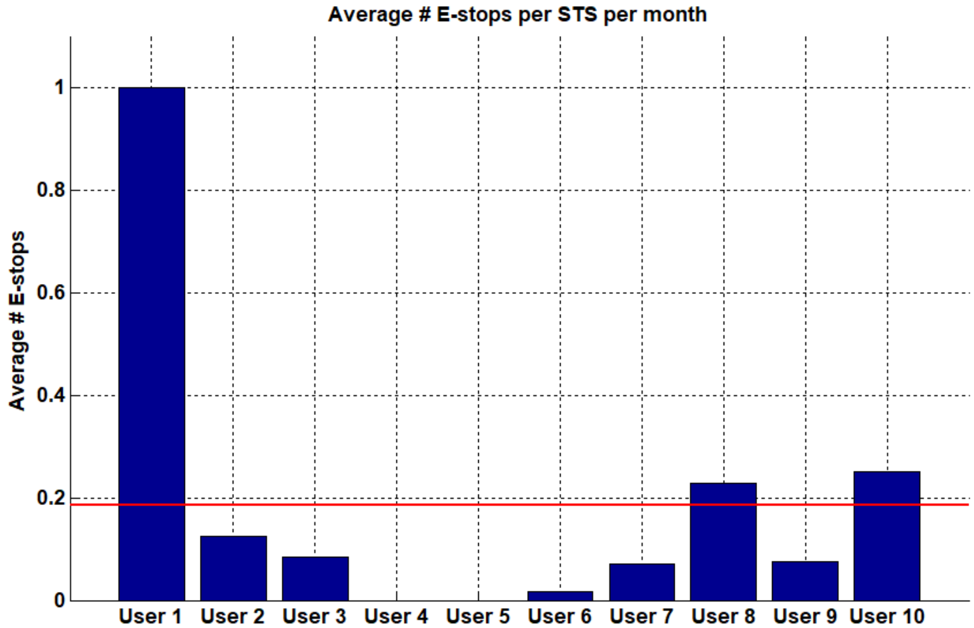


Figure 4 Average amount of E-stops per STS crane per month

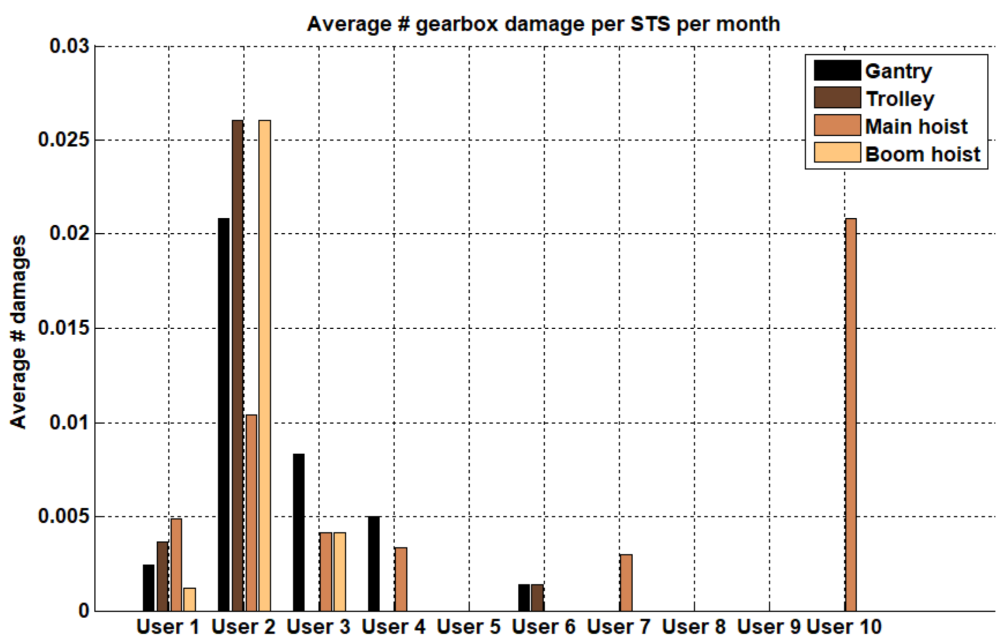


Figure 5 Average amount of gearbox damage per STS crane per month by type

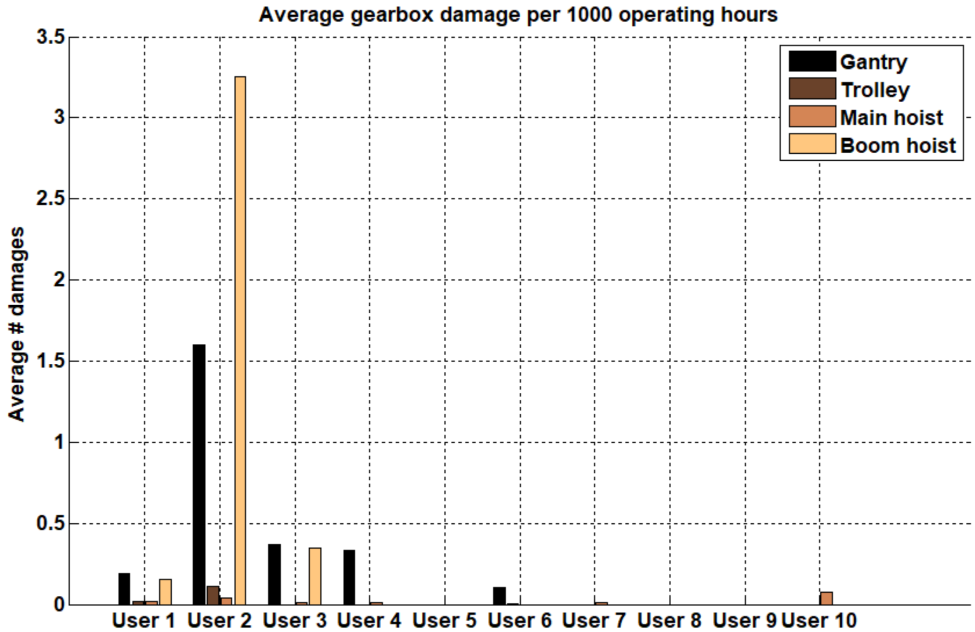


Figure 6 Average amount of gearbox damages per 1000 operating hours by type

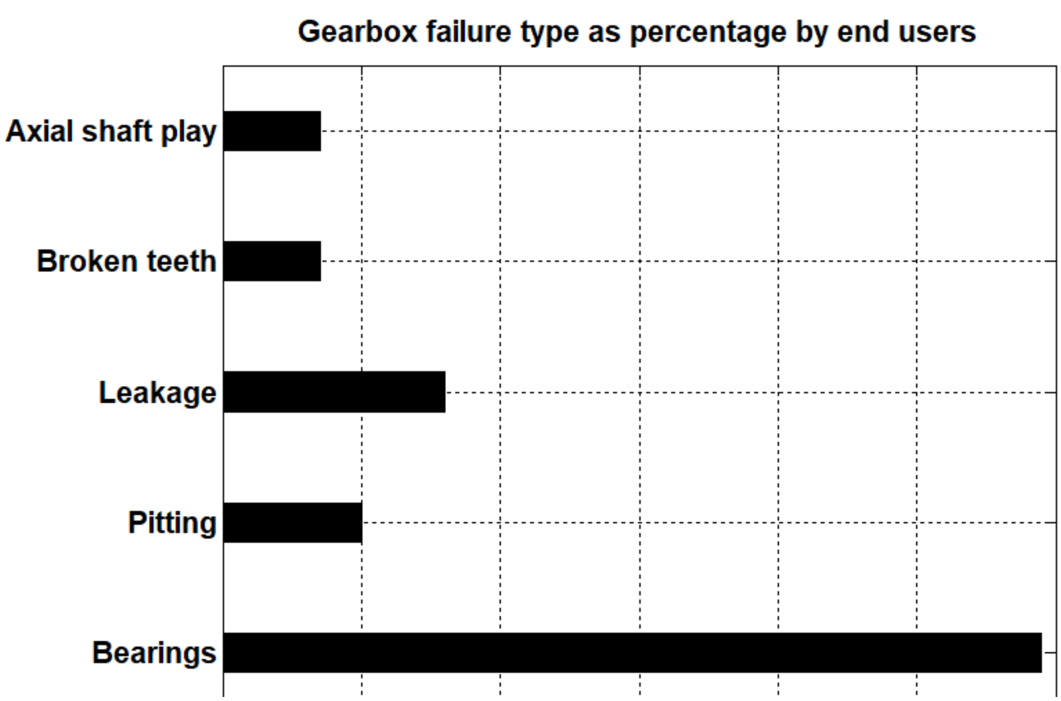


Figure 7 Gearbox failure type in percentage

9. SUMMARY AND CONCLUSIONS

9.1 Following the trend of increasing container ship sizes, container terminals face the need for larger Ship to Shore cranes with respect to hoisting height and outreach. In order to maintain high productivity, operating speeds of trolley traveling and hoisting are increased by installing more motor power.

9. 2 As a consequence, motor physical dimensions also grow with higher rotating masses (inertia) as a result. The action of sudden stops of these types of heavy duty and high speed winches may cause gearbox damage such as bearing damages, gear tooth damages (pitting) or leakage.

9.3 Although hoist gearboxes as well as hoist brakes are described by the general international crane standards, there still seems to be little connection between the two. Gearboxes are usually specified in terms of their fatigue life time and potential overload situations, but often without taking into account the dynamic effects during sudden stops.

9.4 Simulating/calculating the braking process can deliver valuable insight into the effects of sudden stops in the gearbox. Based on the model type (e.g. static or dynamic) and physical parameters that are included, different levels of detail in the results are reached. Even with relatively simple and straight forward calculation models, the effects of sudden stops can be mapped.

9.5 During the dimensioning of hoist winches of STS container cranes, it is recommended to consider the complete winch as a system instead of a group of single components. Terminal operators, OEM's and consultants should be aware of the effects of sudden stops on hoist gearboxes and pay attention to their specifications accordingly.

9.6 A limited research among terminal operators on their experience of gearbox failures provides an insight into the scale of the problems for end users. Although the end user research was only done on a small scale, it still reflects the relevance of the subject topic.

PEMA – Port Equipment Manufacturers Association

Registered Office: p/a Glaverbel Building, Chaussée de la Hulpe 166 Terhulpsesteenweg,
B-1170 Brussels, Belgium
President & Finance Office: Paradiso, CH-6900,TI, Switzerland
Secretariat Office: c/o Baird House, 15-17 St Cross St, London EC1N 8UW, United Kingdom
Secretariat Contact Details: Tel +44 (0)7766 228958 | Email info@pema.org

PEMA
PORT EQUIPMENT MANUFACTURERS ASSOCIATION