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MARITIME CONTAINERS REFRIGERATION PLANT FAULTS SURVEY

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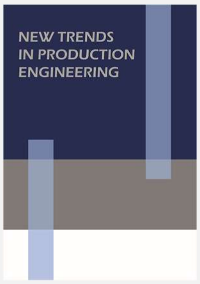

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Abstract. Container transport is the most popular type of sea shipping around the world. The share of reefers (refrigerated container) in the total number of containers transported is about 15%.The worldwide stock of refrigerated containers used for transportation of perishable goods is still growing, while the conventional reefer fleet is shrinking. Still, despite of clean advantages they also carry some risks. Difficult operating conditions of refrigerated containers instigate very high risk of malfunctions, including permanent damage. The majority of articles about refrigerated systems failures, focus mainly on the onshore ones. Publications describing damage of reefers are limited. Therefore, this article attempts to classify and analyze the most frequent failures of container`s refrigeration units. This issue is very important for the crew safety, natural environment and high quality product preservation. The data necessary to perform the analysis come from reports on units damaged over two years. Introduction presents the characteristic of refrigerated containers and problems which occur during their exploitation. Next, the research methodology is presented. Eventually, the research results are presented and discussed. The summary and conclusions close the work.

Keywords: refrigerated containers, refrigeration system faults

INTRODUCTION

Container transportation currently is the most popular type of shipping in the world. They allow relatively fast, inexpensive and safe transport of various loads in standardized containers. This minimizes the risk of damage to the goods during the trip and significantly reduces handling operations in ports. For perishable cargos and ones requiring stable thermal parameters, cooling containers are used. Their share of the total number of transported by sea containers is about 10%-15% (Drewry Publishing, 2014).

Difficult operating conditions of refrigerated containers, cause the risk of disruption or even damage leading to dysfunction to be very high. A chiller's failure during the sea journey, if not removed, can lead to damage to the cargo, and following financial losses. Neglect of technical health and a bad maintenance leads in turn to the need for costly repairs or the port's service call. To prevent all kinds of malfunctions, members of the crew are required to maintain appropriate treatment of refrigerated containers during cargo handling operations, and during the trip. Mainly, the ship's electrician or his assistant carries out systematic control of operation parameters and monitors status of the chillers. In the case of detection of a failure, immediate actions need to be taken, to try to repair the unit or maintain its functionality to keep required thermal performance (Filipek and Śmierzchalski, 2007).

An attempt to classify and analyze the most common failures of chilled containers during transport by sea is taken in this article. The analysis was based on data obtained from the refrigerated containers service company. For the company's sake, its name remains undisclosed. Presented data concern the failures that took place during the carriage of refrigerated containers by sea on one vessel in the period around 2.5 years. Eighteen trips, which transported about 12 770 refrigerated containers were logged at the time.

Container is a thermally standardized container equipped with a refrigeration unit powered with internal or external source of energy. As a load unit it does not differ with dimensions from classic 20 and 40 feet containers. It's made of steel or alloy double wall filled with insulation layer with heat transfer coefficient k < 0.4 W/m2K. Figure 1 shows the front view of the container with integrated condensing unit

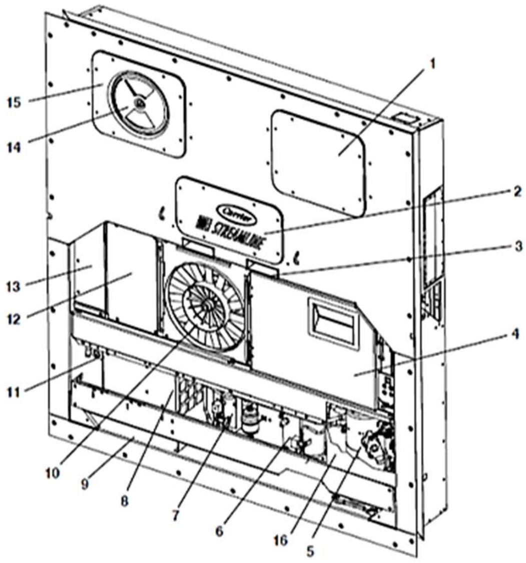

Fig. 1. Front Section of Carrier refer:
1- access panel (evaporator fan #1), 2 - access panel (Heaters, Suction Modulating Valve, Evaporator Expansion Valve), 3 - Fork lift pockets, 4 - Control Box, 5 - compressor, 6 - Receiver or Water Cooled Condenser, 7 - Economizer, 8 - Unit Serial Number, Model Number and Parts Identification Number (PID) Plate, 9 - Power Cables and Plug, 10 - Condenser Fan, 11 - Interrogator Connector (Front left), 12 - Blank Cover (Temperature Recorder Location), 13 - Blank Cover (Lower Fresh Air Makeup Vent Location), 14 - Upper Fresh Air Makeup Vent, 15 - Access Panel (Evap. Fan #2), 16 - Compressor Protection Panel (cutaway view)
Source: (Carrier, 2004)

Refrigerating plant consists of devices, whose task is to maintain certain level of thermal parameters in the cargo area of the container during transport and storage. Generally, following subsystems can be distinguished in the chiller: refrigeration, power supply and control and monitoring. As a result of the interaction of these subsystems full automation of containers operation is possible, limiting the maintenance to periodic inspection of operating parameters. All components are directly or indirectly related to each other, irregularities in the functioning of one of the elements has an impact on the work of others.

Modern refrigeration containers cooling systems are based on the single-stage refrigerant circuit with recuperative heat or with economizer and vapour injection to the compressor. Such solutions are used mainly to improve the working conditions of cooling. Thanks to the recuperation of heat, subcooling liquid refrigerant leaving the condenser, which allows the heat gain (increase in unit cooling capacity). This is done at the expense of increased work (increase in power demands of compressor) and increased temperature of refrigerant at discharge. Nevertheless, energy and movement efficiency benefits come in favor of this type of solution usage. In case of a circuit with economizer, the same sub cooling of liquid refrigerant routed to the expansion valve effect is obtained and additionally the pressure on compressor’s intake increases. Example diagram of the refrigeration system with economizer is shown in Figure 2. Refrigerants used in refrigeration containers are primarily R134a and R404A. R134a is a homogeneous substance.

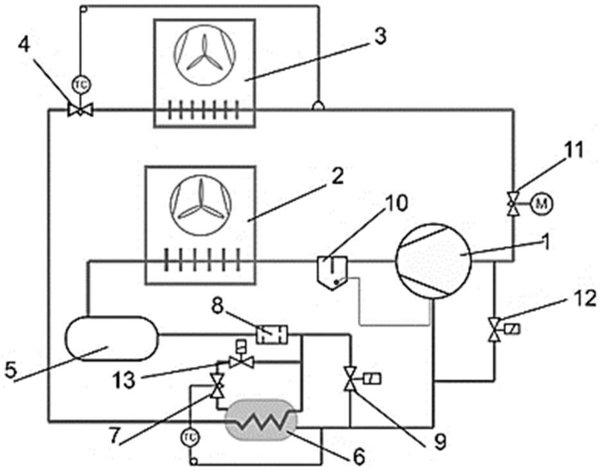

Fig. 2. Refrigeration Circuit Schematic:
1 – compressor, 2 – condenser, 3 – evaporator, 4 – thermostatic expansion valve, 5 – receiver, 6 – economizer, 7 – thermostatic expansion valve, 8 – drier, 9 – Liquid Injection Valve, 10 – oil separator, 11 – SMV valve, 12 – Unloader Solenoid Valve,13 – Economizer Solenoid Valve

Thermal load of refrigeration systems varies over time and depends on a number of factors. Hence, there is a need to adapt the performance to the instantaneous heat load. This is particularly important in the case of reefers, which very often are designed to work in a very wide range of temperatures. Continuous adjustment of performance is achieved by changes in pressure of refrigerant and its temperature of evaporation. In the Carrier aggregates it is accomplished by the use of SMV and LIV valve (Carrier, 2004). In this system intake compressor's stream is reduced, and refrigerant's pressure and temperature of evaporation is raised. This leads to an increase in the work of compression and temperature rise at the end of the compression ratio.

Monitoring and control of reefers are based on microprocessor systems. Drivers are equipped with modules to register data and parameters of refrigeration systems and cargo. For security reasons, the cooling units also have the ability to be controlled manually in a fail-safe mode. Modern units are designed to work with both marine and terrestrial powering networks. Plugs and sockets of connecting cables are standardized. Connectors are designed to be operated only when the voltage is disconnected with manual switch at the slot. Consequently, switching the voltage is possible only when the plug is in the socket (Daikin Industries, LTD, 2006), (StarCool, 2008), (Thermo King Corporation, 2010).

METHODOLOGY

Data which are the basis for analysis come from reports on damaged aggregates on a vessel during its trips. Report form is unified with a sheet, to clearly identify the device and the damage suffered. The report is a series of detailed information consisting of: a description of the damage, its duration, and characteristics of activities that taken in order to remove it. There are also data on: thermal parameters in the container and what correct values should be, the refrigeration circuit parameters – temperatures and pressure or amount of ventilating air. The data collected concern the four producers of aggregates, marked: A, B, C and D.

Damage can be defined as any event, whose consequence is partial or full loss of operational performance. In the literature on the subject several different classifications of refrigeration damages can be found. In work of Zakrzewski (Zakrzewski, et al., 2011) on land-based refrigeration, there have been 10 categories described: I-failures related to refrigerant leaks and leaky installation, damages to refrigerating aggregates, III-failure of condensers, IV-evaporators' failures, V-failures associated with driver units, automated control and protection, VI-defrosting systems malfunctions, VII-damage to the condenser's and evaporator's fans, VIII-powering system failures, IX-damages to additional equipment, X-alarm installation failures. In the work of Kostrzewa and others (Kostrzewa, et.al., 2016), presenting an analysis of refrigeration damages on fishing boats, only 7 categories of damages have been listed. In

turn, Francis and others (Francis, et al., 2017) mention as many as 18 groups of damages, characterizing detailed issue placement: I-pipe or joint failure, II-other (nor stated), III-Leaking seal/gland/core, IV-Fracture/rupture/crack, V-mechanical component fault, VI-ancillary component (fan/pump), VII-leaking flange/union/joint/, VIII-abrasion/water through, IX-monitor/control H'ware (transducer etc.), X-moisture issue, XI-physical damage (3rd party), XII-Dirt/corrosion/ blockage, XIII-electrical/electronic hardware, XIV-Vibration, XV-Lose the Item/cap/seal, XVI-missing cap/seal-software/programing, 18^{th}-alarm hardware (sensor, etc.).
The classification proposed by Zakrzewski significantly narrows the field of analysis. For example, damage associated with presence of moisture in the refrigerant, can be mistakenly interpreted as a failure of the dryer, while the problem is associated with the refrigerant. Similarly, the classification of defects proposed by Kostrzewa is too general in some points, making detailed analysis of the damage difficult. In turn, in the work of Francis, gives a very precise classification that allows for detailed analysis and accurate identification of damage, however, does not fully explores problems associated with operation of refrigerated containers transported by sea. Hence, it was decided to develop a new classification of damages suitable for such containers.
The development of the damages' classification starting point was an assumption that refrigeration is a set of interrelated subsystems. The most important of them being: *Mechnical components* including compressors, heat exchangers, fittings, piping, valves etc., *Control system* with sensors, drivers, etc., *Power system* including relays, fuses, power cables etc. During cooling system's analysis, matters related to the refrigerant can't be skipped neither. Competent filling of suitable refrigerant or its purity often are factors that determine proper operation of an aggregate. Hence, in the first stage of the research four main groups were established: I. Refrigerant faults, II. Mechanical Component faults, III. Control system faults, IV. Power system faults.
After preliminary examination of damage reports, it turned out that proposed classification is not sufficient for precise description of the damage. Then, it its modification was decided. To the four already mentioned groups additional three were introduced: V. Defrosting faults, VI. Others/not stated faults, VII. Human faults. In some cases, it is difficult to say without a doubt whether the event is a result of human error. However, events consisting of disconnecting the aggregate's power cord by port support unit were found in examined reports, which is clearly a human error leading to dysfunction of the device. Also, some unidentified events were reported, which were included in presented classification – Others/not stated. On top of it, the first four groups are divided into subgroups, to allow for precise description of an event. Figure 3 shows the detailed classification of the damages.

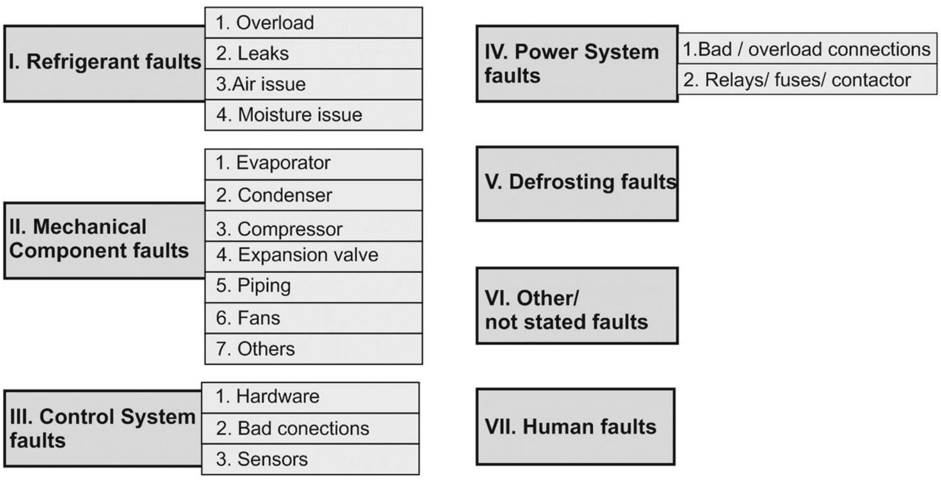

Fig. 3. Refrigeration system fault types'.

On the basis of the developed classification a Microsoft Excel sheet was prepared, with purpose of organizing damages by category and manufacturer. In the worksheet an information about operations on refrigerant was also provided, i.e.. an amount added to the installation in kg, a leak placement.

RESERCH RESULTS

Aggregates' damage analysis presented hereby, concerns events that took place during the sea carriage of containers on a ship with 5450 TEU capacity. The vessel is designed to carry 1 600 standard 20-feet refrigerated containers. Interview with the crew and data collected indicate that a maximum 900 refrigerated containers have been transported at a time – while 700 on average. The time horizon of the study amounted to two and a half years, during this period the ship did eighteen trips. Refrigerated containers from four different producers were present. During the period covered by the survey, 394 damages to chillers were reported. On average, 3% of transported refrigerated containers have failed during a single voyage. Out of all recorded events, 33% were A, 33% producer C, 28% producer B, and 6% D. Total amount of refrigerant that was used to keep refrigeration functional during the period stood at 289.2 kg. Most of which was a R134a, with total 224 kg used. The remaining amount was a R404A. Figure 4 shows a share of particular damage groups in total malfunctions recorded, all producers considered.

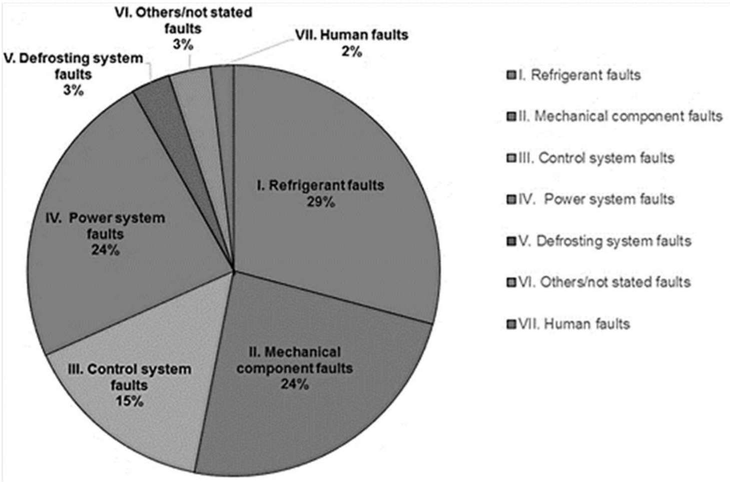

Fig. 4. Percent of refrigeration system faults'.

Close to 29% of the recorded events are associated with refrigerant. Similar quantites can be found in the work of Kostrzewa and others (Kostrzewa, et.al., 2016). On the other hand, in the work of Francis and others (Francis, et.al., 2017) refrigerant-related failures were up to 66% of the total number of events. This discrepancy derives primarily from operating conditions and size and construction of the refrigeration system. Damages associated with the components of a refrigeration system (i.e., compressor, condenser, evaporator, expansion valve etc.) accounted for an average of 24% of the total number of events, similar to power system failures. Damage to the control system accounted for 15% of the total number of recorded events. The remaining groups combined does not exceed 8%. Therefore, almost two thirds of failures were affected by three groups: Refrigerant faults, Mechanical component faults and Power system faults. In author's opinion, half of these faults could be avoided if e.g. during loading and unloading of container as well as during refrigerant charge or refiling the procedures were followed.

Detailed failure analysis of Group I (Refrigerant Faults) revealed that more than 72% of the events concerned the leakage of refrigerant. They happened mainly on pipeline connectors with filter-dryer and service valves (on the tank or the compressor). Also a single case of mechanical damage to the piping itself was registered, effecting with a leak. However, due to the compact design of the refrigeration system and its development, this situation is rare. Another, rather heavy failure of refrigerant was its moisturizing. On average, 20% of the refrigerant related events is due to moisture. Only 5% of the damage were cases of air trapped in the installation and only 2.6% of the cases the installation overloaded with refrigerant. In the second group of damage (Mechanical Components Faults), more than 39% of the events concerned the electronic expansion valve. Based on the collected data, it was found that the most common cause of this malfunction was either dirty or icy coil. 26% damages qualified for this group were related to fans forcing the air flow through heat exchangers. Noticeably, much more common were failures of evaporator's fans. Nearly 20% of the events were damages to compressors. There was also a 14% share of damages related to valves: SMV, LIV, etc. Damages to the control system (III) in 61.6% of the cases were caused by errors or dysfunctional sensors (temperature, pressure). Almost 29% of the events included driver damage. The 3.33% were loose wires. Almost 65% of the power system failures (IV) were caused by burned-out relays/fuses or contacts. The remaining 35% were cases of burned/mechanically damaged power cables. Significantly, this last subgroup was often caused by not following the procedures.

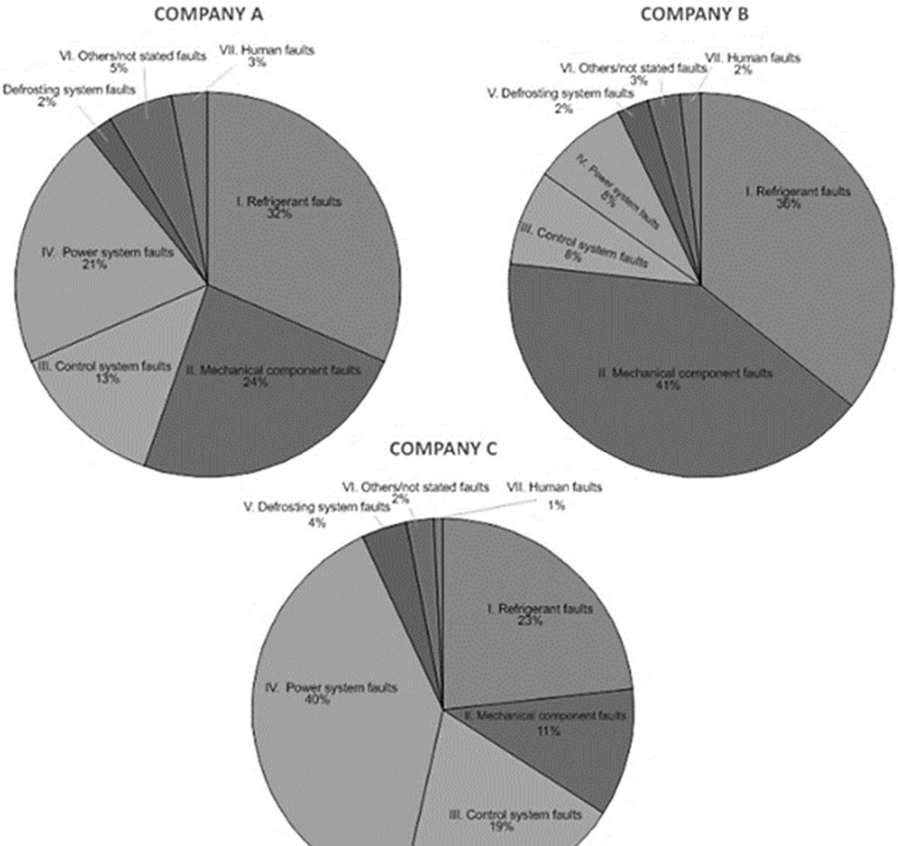

Fig. 5. Comparison of refrigeration system fault types for three companies.

Comparing the damage statistics for the three companies A, B, C, a significant differences between them is visible, as graphically shown in Figure 5. These disparities result mainly from the different construction and equipment used in considered aggregates. For example, chiller A is equipped with a thermostatic expansion valve, while company B units use an electronic expansion valve. In the company B units among 46 registered damages, over 71% were of the expansion valve. While the company A, only 6% of 31 reported damages related to this part. Significant differences in the occurrences of power and control systems are also visible. For company C, close to 40% of all damages happened to the power system, while for the company A it was only 21% and for B 8% respectively. In case of control systems the largest frequency of malfunction was also reported for company C. for A and B this rate was respectively 13% and 8%, while company C got 19%.

As for the I group of damages (refrigerant faults), each of the companies averaged to 70% of failures being from refrigerant leaks. The other categories significantly differed. In the company A units presence of moisture in the installation was identified 12 times, which accounted for 29.3% of all damages the refrigerant. In contrary, company B units had only 7 such cases, being 17.5%, and company C – 4 being 13.3% of total.

CONCLUSION

The classification of reefers refrigerant plant faults has been presented in this paper. Faults were divided into seven main categories, some of them have been subdivided. This allowed to archive precise characteristic of faults. An analysis of refrigeration plant damages have been done according to this classification. The analysis includes
only those reefers' faults which take place during sea transportation.

Based on the obtained results, it was found that the most common cause of refrigerated container aggregates' dysfunction is a refrigerant leak. This is mainly due to the difficult operating conditions of the reefers. Nevertheless, there are cases of non-compliance by the service personnel during filling or topping up of installations leading to moisture or aeration and sometimes to the leakage of the refrigerant (e.g. closed service valves). During the research, cases of overloading the system were also identified. This clearly indicates a service error. Damage of the mechanical components of the refrigeration system was also a frequent cause of the object's dysfunction. Almost two thirds of failures were affected by three groups. In author's opinion, half of these faults could be avoided if e.g. during loading and unloading of container as well as during refrigerant charge or refiling the procedures were followed.

The presented material is merely an introduction research on faults that occur during the operation of refrigerated containers, their impact on the natural environment and its economic aspects.

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