Automatic (un-) locking of twist-locks at maritime containers

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ABSTRACT

The paper describes the problem of automatic mounting and dismounting of twist-locks at maritime containers. This task is very complex due to various container sizes and various twist-lock types. A manipulator mechanism, operating in a twist-lock station, is the basis for the preferred solution. The end-effector comprises a universal device to rotate the cone of the twist-lock and a gripper. Compliance effects of the gripper have been investigated. They can be used advantageously to overcome misalignment during grasp and to protect the manipulator against overload.

keywords: automatic mounting, twist-lock, parallel gripper, friction compliance

1. INTRODUCTION

Twist-locks are used to secure containers at deck of a seagoing vessel. Four of them have to be inserted in the bottom corner castings of a container before the quay crane can place it on top of a lower container at deck. The so-called semi-automatic type of twist-lock connects automatically to the corresponding top corner casting. The use of such twist-locks avoids that personnel must be at deck during the hoisting process of the container. At present the procedure to connect (insert and lock) or disconnect (unlock and remove) twist-locks usually takes place manually at the quay, under the crane by terminal personnel.

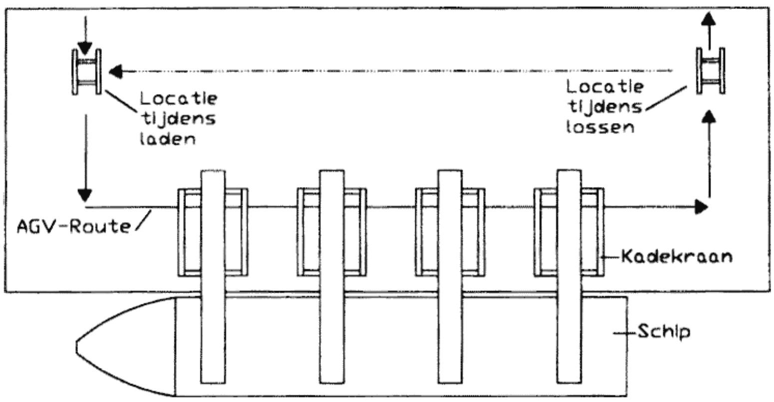

Fig. 1 Typical terminal layout

A typical terminal layout is depicted in fig. 1. Several quay cranes ("kadekraan" in Dutch) are working at the same time to make the transhipment time as less as possible. Carriers at the quayside bring the containers to and from the stack. For ease of traffic control they drive usually in a sort of circuit, which make it possible to use automatic guided vehicles (AGV's) as carriers. There are enough carriers to supply the cranes with containers; the cranes are supposed to operate without delay.
The present manual twist-lock connection process has two disadvantages:

- it needs extra time of the crane cycle (using two persons, one at each container side, the delay is estimated to be 15 s extra to an average crane cycle time of about 90 seconds)
- the working place, under the crane and near the driving lanes of the carriers, is still not safe.

A further automation of twist-lock connection is thus very interesting. Investigation of the global problem has finally lead to the insight that a separate twist-lock station is a favourable basis solution. Such a station can serve more than one crane. It should be movable to operate either before or after the cranes, in the path of the carriers. Both positions of the station have been drawn in figure 1. In or near this station, storage of the twist-locks coming from the ship must be present. The storage bin used until now is not suited for automatic supply of the twist-locks.
A complication for automation is the variety of twist-lock types. Several manufacturers of twist-locks are in

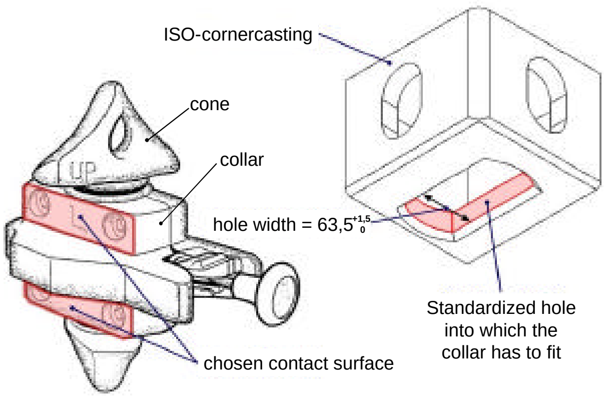

Fig. 2 Example of a semi-automatic twist-lock

competition to develop easy-to-use types, which cannot be used in a wrong way and which will never fail to lock. The recent types have a housing and a spring-loaded shaft with two cones at the end. They differ for instance in the shape of the cones, their relative shaft angle and the attributes (handle) to move and click the cones at one of the three predefined rotation angles. An example of a semi-automatic twist-lock has been depicted in fig. 2. The mass of a twist-lock is usually 7 – 8 kg.
Some crucial aspects of automated mounting and dismounting will be regarded further in this paper. A conceptual description of the twist-lock station, comprising a manipulator, will be presented in chapter 2. The design of the end-effector, which contains a gripper and a cone rotator, will be given attention in chapters 3 - 5. The compliance behaviour has been analysed with a theoretical model (chapter 6). Correct working of the end-effector has experimentally been verified. The results will be reported in chapter 7.

2. THE TWIST-LOCK STATION

Naturally such a station should contain four independently working manipulators, one at each corner of the container. To determine the kinematical type of manipulator the following observations were made.
The containers can be brought in the station only with limited accuracy. The position accuracy of a container in the horizontal plane is approximately 5 cm. In is not a good idea to perform accurate positioning with the heavy container carrier. Motion control of the manipulators is required anyhow and this control may include adaptation to the container position.
The length dimension of containers can vary. The most popular sizes are 20 feet and 40 feet. The manipulators must therefore be guided (rail mounted in the station) to adapt to the container length.
The working area of the manipulator depends not only on the position of the corner casting of the container, but also on the storage position for the twist-locks. An interesting idea is the use of trays, which are provided with the same holes as the corner castings. The twist-locks can be placed in these trays, using the same tool needed

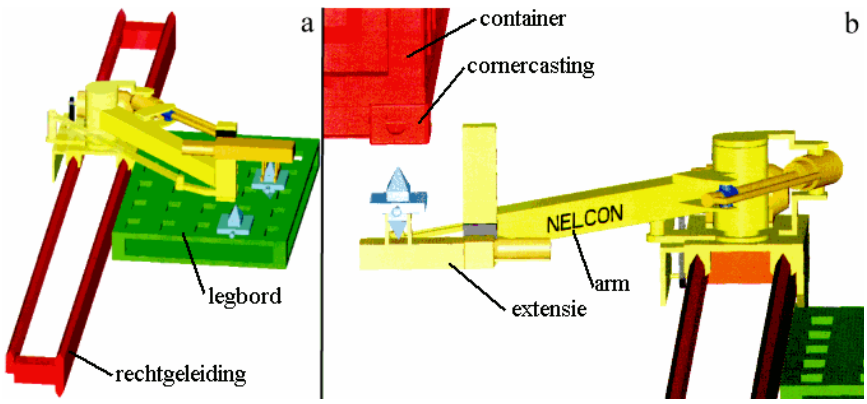

Fig. 3 Manipulator concept

for (un-) locking them at the container. Either the tray must be upside down, or the twist-locks must be rotated 180 degrees. Without further discussion the latter possibility will be accepted here. The tray must be placed at the other side of the guiding rail. The working area is thus about 1 m at both sides.
Except for the upside down rotation, the twist-lock itself needs no other change of orientation. Mechanical arrangements like parallelograms or rectilinear guiding can be used to simplify the manipulator. A nice configuration is depicted in fig. 3 [1]. A planar parallelogram eliminates the rotation of the end-effector. The end-effector needs a vertical movement to insert the twist-lock. The vertical guiding elements should preferably not reach under the container. The eccentricity ("extensie" in fig. 3) of this gripper is advantageous for the working range above the tray, when the gripper is used upside down. The length of the parallelogram arms can be shortened then. This manipulator has three degrees of freedom: translation horizontal, rotation (of parallelogram arms), and vertical translation. Further information can be found in [5].

3. THE END-EFFECTOR

The end-effector is supposed to be a universal tool, which means it must be able to mount and dismount all types of semi-automatic twist-locks. The mounting process consists of two parts: grasp of the twist-lock housing and rotation of the shaft with the cones. Regarding the universal aspect, it has been observed that:

- To grasp the twist-lock a common part of the housing must be available. The only common surfaces of the various twist-lock types are those of the collar matching with the holes in the corner castings, see fig. 2. A universal gripper seems to be very well possible. Details of the gripper design will be given in the next chapters.
- The handles for manual shaft rotation differ very much, and no inspiration was found to operate such handles with some common device. The only possibility seems to be to rotate the lower cone directly. Those handles were added to make manual rotation easier, but nevertheless direct operation of the cones is always possible. The extra handles might hinder the operation of the end-effector. Therefore the end-effector must be designed regarding as much as possible types of twist-locks. The nut to rotate can be any shape that fits around the cones. The spring of the shaft will give the cone a unique orientation relative to the nut (form closure in one direction). The control of the nut rotation can move the cone to any wanted orientation. Just the predefined positions of each twist-lock type must be known on beforehand. In this paper no further attention will be given to the cone rotation.

It was concluded that automatic (un-) locking of most types of semi-automatic twist-locks is possible. These types have one shaft at which two cones, one at each end, are fixed. These types are used widely and can be regarded as the standard group.

4. DESIGN DEMANDS OF THE GRIPPER

The container can move due to external disturbances, while resting on a rolling chassis with pneumatic tyres. The wind is an example of a disturbance that can generate fluctuating forces on the side of the container, which can result in an oscillating movement. Due to the possible movement of the large container mass (30 ton) and the robust construction of the twist-lock the gripper will have to be compliant to prevent damage to itself or other components of the robot. Mechanical compliance will help tackle the problem of the moving pickup point on the container and keep the required control system simple. Such compliance can be added to the drives (e.g. use of a pneumatic driving cylinder) or as elastic elements in the gripper or in the manipulator.

The collar was chosen as contact surface for the gripper, because it is the common element in different twist-lock designs. It has to fit into the standardised hole of the corner casting, so the shape and size will be roughly the same. Although the width of the hole is only allowed a tolerance of 1.5 mm, the collar widths found in practice can vary between 57 and 62 mm. This 5 mm range in collar sizes had to be taken into account for a reliable operation of the gripper.

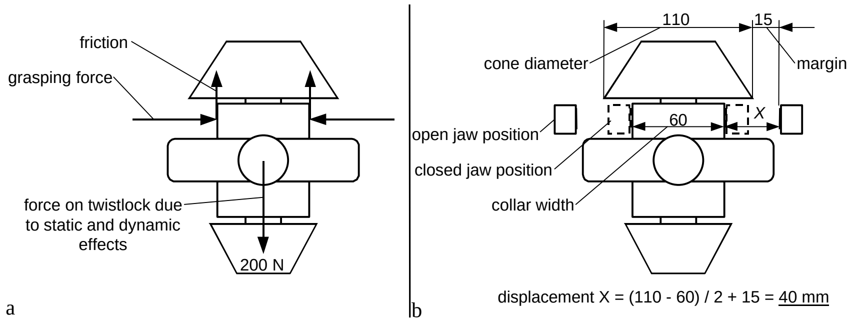

Fig. 4. Gripper demands

In fig. 4a the forces to be applied by the jaws during a grasp are presented. The frictional forces generated on the collar sides will have to be sufficient to compensate the static and dynamic forces exerted at the twist-lock. The total force (F_{tot}) that has to be compensated in a direction parallel to the collar surface is assumed to be 200 N. With a frictional coefficient (μ) of 0.125 the grasping force exerted by each jaw (F_{jaw}) should be 800 N then. This is the minimal force that has to be guaranteed during the manipulation of a twist-lock, for all collar sizes. Fig. 4b shows the open and closed position of the jaws. It shows how far the jaws have to open, during the positioning of the open gripper. There has to be enough clearance between the cone and jaw to prevent a collision, because the cone diameter is larger then the collar width. To get a clearance of 15 mm the displacement of a jaw has to be 40 mm.
The embodiment of the end-effector, comprising the gripper and cone rotator, should be sufficiently compact. This is mainly because a twist-lock must be inserted at the storage tray, where neighbouring twist-locks can be present. Collision with these other twist-locks is not allowed,

5. CONFIGURATION OF A PARALLEL JAW GRIPPER

An existing gripper that is capable of producing a rather large clamping force and large displacement is illustrated in fig. 5a [3]. It consists of two parallel jaws, actuated by a double acting pneumatic cylinder. Attached to the cylinder's piston rod is a dual rack gear, which drives two partial sectors of pinion gears. Two pairs of the symmetrical arranged parallel closing linkages are mounted directly on the partial sectors of the pinions and provide the clamping force.

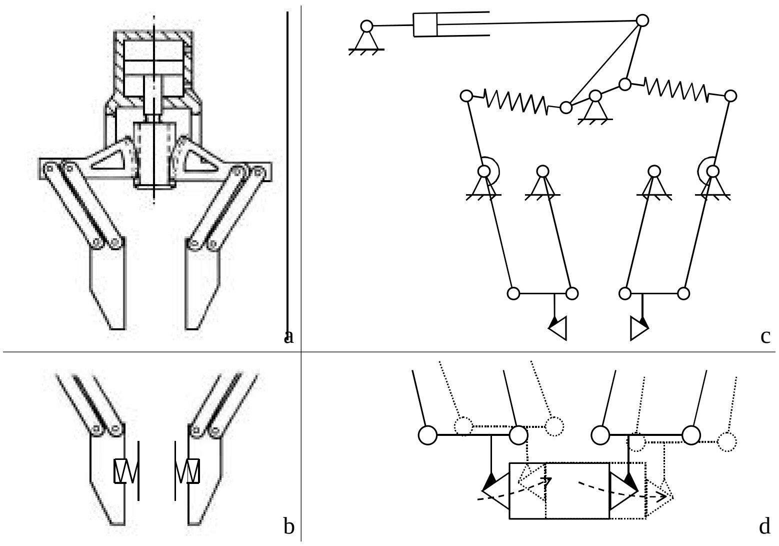

Fig. 5 Parallel jaw grippers

This design only features compliant behaviour with respect to the width of the grasped object. If the grasped object is larger then the distance between the closed jaws, they will come in contact with the object before they are fully closed. Therefore the piston will not travel to its end position during this closing operation. This makes it possible to grasp different sized objects. It will however be more difficult to sense the closed position of the jaws. A special sensing method like force detection will be required to measure the closed position.

The gripper configuration of fig. 5a can be given additional compliance as shown in fig. 5b. Preloaded springs have been added to the jaws, to get compliant behaviour in the horizontal direction. Preloading the springs gives two advantages. First of all, the stroke required to build up sufficient grasping force can be short. If the preload is set to the minimal required grasping force, after contact with the object the springs hardly need any travel for a secure grip. Secondly the minimal required grasping force can be guaranteed with the aid of a proximity sensor that can detect the end position of the pneumatic cylinder. If the cylinder reaches the end of the closing stroke with an object between the jaws, the springs will have been pressed in and the grasping force would at least have to be equal to the set preload.
This gripper design with springs in the jaws was not used for the twist-lock manipulator, because the springs take up to much space. Special measures would have to be taken to keep the jaw construction sufficiently compact.

An alternative configuration with spring elements can be seen in fig. 5c [2]. The preloaded springs are not directly connected to the jaws, but they have been placed between the actuator and the lever of the jaw parallelograms. The mechanism amplifies the force of the cylinder, when the jaws are closing, if the springs would have been ordinary bars. The generated grasping force is largest when the jaws are nearly closed. The more they are opened the smaller the possible force, but the larger their displacement versus the cylinder displacement.

In this configuration another effect is introduced with respect to compliant behaviour. If a horizontal force is applied, a resistance is generated by friction in the contact surfaces. The horizontal force has to be large enough to overcome this resistance and to move the jaws with the object in between.
The cause of this effect is illustrated in fig. 5d. When the grasped object moves to the right the left jaw swings up and the right jaw swings to a lower position while they both remain parallel to each other. This causes the jaws to slide over the surface and generate frictional forces if the grasped object does not change orientation. In the example case the twist-lock will not change orientation, because it is fixed to the container during the grasping manoeuvre. It can only move with the container in the horizontal direction.
The design in fig. 5c will be considered further for the twist-lock manipulator and will be analysed with respect to its force transmission and its compliance effects. The embodiment of the gripper is depicted in fig. 8.

6. ANALYSIS RESULTS

Use has been made of a standard computer program for kinematic and dynamic analysis [4]. Here only a static force analysis was required.

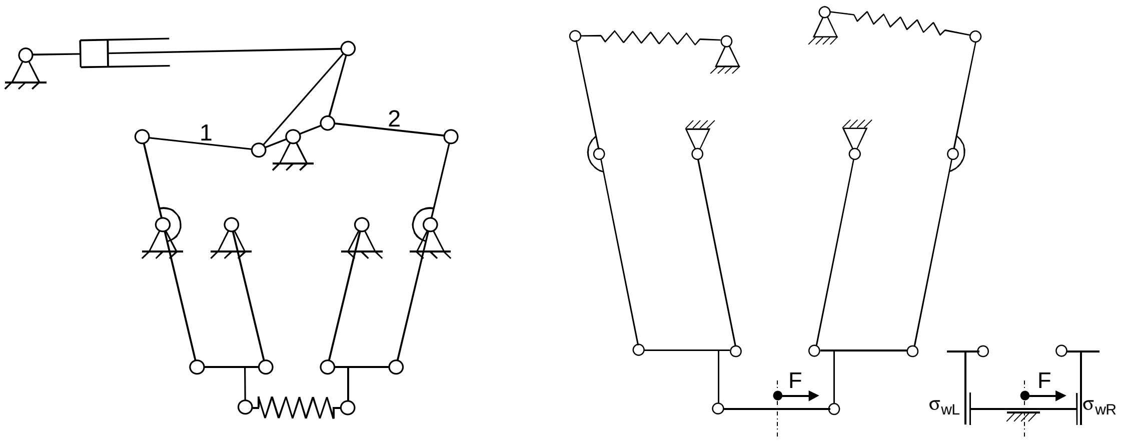

Fig. 6 Mechanism model for analysis of force amplification (left) and compliance (right)

To demonstrate the driving force amplification, the mechanism has been modelled as in fig. 6 left. The twist-lock has been replaced by a pressure spring, having a characteristic as drawn in fig. 7 (grasping force). The preload of this spring is chosen to be 400 N. Contact force will be built up after that the jaws are in contact with the twist-lock. Further closure is possible due to the elasticity of the spring. The contact force rises (negative, pressure in the spring), but the required driving force will be reduced, see fig. 7. The picture shows the analysis results for the smallest and largest size of twist-lock (collar width d=75 and d=62 mm). Based on this information it is possible now to choose a pneumatic cylinder that produces always enough grasping force (minimum 800 N), the worst case is for the smallest collar.

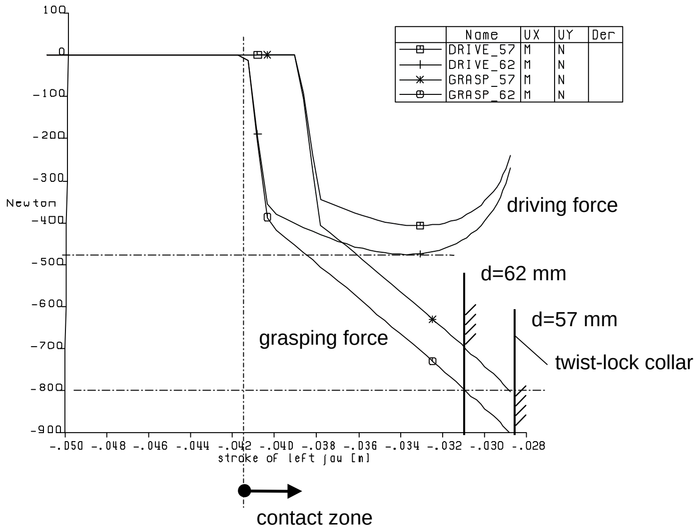

Fig. 7. Force transmission

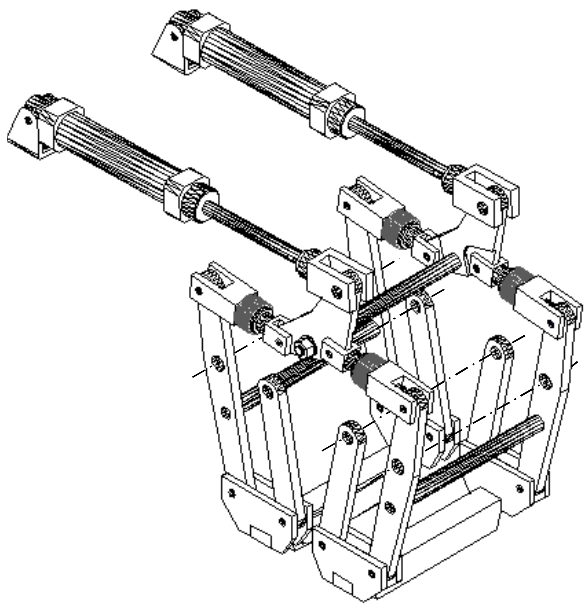

Fig. 8. Gripper embodiment

To obtain compliant behaviour of the gripper, in reality springs were applied for the bars numbered 1 and 2 in fig. 6 left. Their characteristic was chosen such that they have about the same effect at the jaws as indicated in fig. 7. To investigate the compliant behaviour the cylinder can be placed in the “out”-position. Observing that the immovable parts can be left out, the mechanism model of fig. 6 right must be investigated. An external force F can be applied as the input of the model, the horizontal displacement shows the compliance then.

Fig. 9 shows the result for various widths of twist-locks, when no friction is assumed. Obviously there is a small range in the compliancy characteristic for all twist-lock sizes. It can be estimated that position errors (misalignments) of the gripper of about 3 mm will not introduce a problem for correct grasping.

Figure 10 shows the result for collar width d = 60 mm and friction coefficients μ ranging from 0.0 to 0.6. Now the hysteresis effect can be recognized very well. It is responsible for extra resistance, such that a side force of 80 N will not displace the twist-lock (for μ = 0.4 and higher). This important because the twist-lock is supposed to be turned upside down. Halfway, when the gripper is horizontal, the gravity force of the twist-lock mass has precisely the value 80 N. The gripper can do this rotation without side movements of the twist-lock with respect to the gripper.

7. EXPERIMENTS

The twist-lock manipulator has been built partly for test in a laboratory environment. A corner casting was fixed to a frame, and only one storage position has been created. The end-effector has been built completely, including sensors for control of driving motion and detection of the corner of the container. The parallelogram arms and the slider to which they are to be mounted were left out.

During the test the manipulator proved itself, being capable of a secure and reliable grasp of various types of twist-locks.

Tests were also done to give an indication of the gripper compliance. The maximum amount of static offset was measured that would still allow a problem free manipulation. The result for two twist-locks with different collar widths (59.5 and 62 mm) is:

- twist-lock 1 (collar width = 59.5 mm), maximum offset: 7 mm
- twist-lock 2 (collar width = 62 mm), maximum offset: 4 mm

The tolerances between the collar and corner casting can only partly be responsible for this offset. Obviously the larger amount of the offset has been made possible through the gripper compliance.

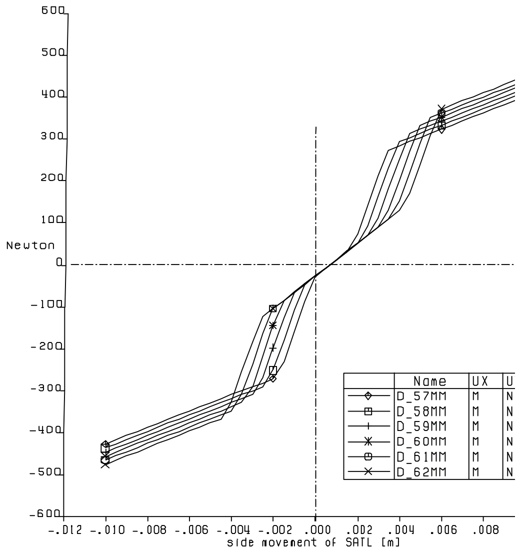

Fig. 9 Compliance characteristic without friction

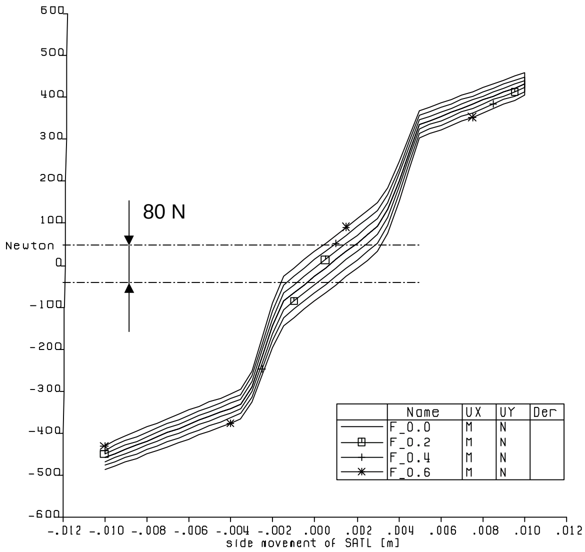

Fig. 10 Compliance characteristic with friction

8. CONCLUSION

The twist-lock project of the TU Delft has proved that automatic (un-) locking of various types twist-locks at maritime containers is possible. This is due to the successful design of a universal gripper and rotation unit. The manipulator with this end-effector, applied in a twist-lock station, is a basis for further automation of container terminals. With regard to the heavy mass of the container and its position inaccuracy, a compliant gripper has been investigated and found to be very useful for this application. The preload of the springs guarantees sufficient grasping force, without need of force control. The compliancy effect includes extra resistance due to friction in the gripper mechanism. This is beneficial for misalignments and damage prevention.

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