Műszaki Tudományos Közlemények vol. 19. (2023) 44–50.
DOI: Hungarian: https://doi.org/10.33895/mtk-2023.19.07
English: https://doi.org/10.33894/mtk-2023.19.07

COVERING ELEVATOR DOORS AND DECORATIVE ELEMENTS WITH A PROTECTIVE FILM

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Abstract

In today's world, in order to maintain competitiveness, all companies strive to meet deadlines and sell their products to their customers in the best possible quality. Also, they want to produce these products as cheaply as possible. This is no different in the elevator industry. At Wittur Hungária Kft., we produce thousands of elevator doors or their decorative elements every year, which must be provided with a protective film on a painted or structured surface, thus ensuring that the customer receives the quality product they expect. The main reason for the design of the machine is to speed up and automate the foiling process, while increasing productivity and reducing costs. Therefore, we set out to design a machine with which we can make the work of the workers easier and faster, since this operation is currently carried out manually, and we also ensure a consistent quality with the least possible human intervention.

Keywords: *elevator, foiling machine, machine design, finite element method, automation.*

1. Limitations of Current Technology and Advantages of Planned Development

Currently, our company relies on a completely manual process for foiling elevator doors and decorative elements. This requires the worker to guide the foil by hand and cut it manually to size. The process is further complicated by the fact that the worker must walk alongside the stand, causing discomfort and fatigue. The new foiling machine will not only streamline the process and improve productivity, but it will also enhance ergonomics and raise the standard of work.

The limitations of our current technology also make it difficult to apply foil to wider or taller elements that hang off the table. To ensure full coverage, extra foil must be used, and the element must be moved several times, significantly slowing down the foiling process. With the new machine, we can overcome these limitations and achieve faster and more precise foiling.

The current manual foiling process only allows for one element to be covered at a time. However, with the new design, up to four elements can be foiled in a single cycle, resulting in increased productivity and reduced operation time (**Table 1.**).

Currently, the quality of the foiling process is inconsistent, often resulting in wrinkled or stuck film and unnecessary film usage. Workers may also cover elements at an angle, requiring multiple foils and increasing costs while also harming the environment. The new machine will improve the quality of foiling by ensuring precise and even coverage while reducing the amount of film used.

Table 1. *Current technology*

Technology parameters	Current foiling	Machine foiling to be introduced
Productivity	2 pcs/min	3-4 pcs/min
Maximum width	795 mm	1000 mm
Maximum element length	2450 mm	3300 mm

1.1. Detailed presentation of current technology

To begin the manual foiling process, the worker places the item on the foiling table and positions it in front of the foil roll. The worker must ensure that an adequate amount of protective foil is applied to both the top and sides of the element, using both foils for larger elements. Next, the worker pulls the foil over the element and smooths it along the edges, repeating this process for larger elements until they are completely covered. Once the element is covered, excess film is cut by hand using a scalpel, and the film is then smoothed on the other side of the element (**Figure 1.**) **[1]**.

Figure 1. *Current technology.*

2. Creation of the construction of the new machine

The construction of the new foiling machine began with the tallest and widest door produced by the company, which measures 3020 mm in height and 930 mm in width. To ensure that the machine can accommodate elements of all sizes, It has been designed with slightly larger dimensions (**Figure 2**) **[2].** This will ensure that the protective film can be applied to elements of any size without any issues.

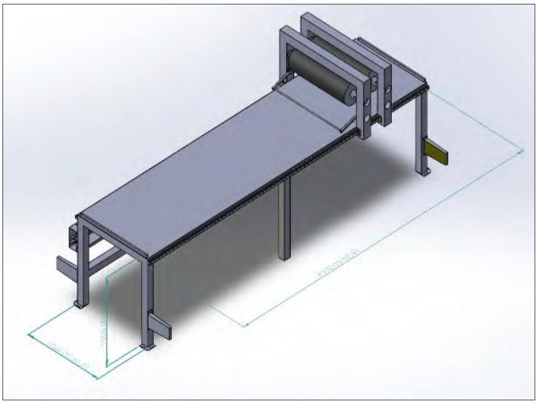

Figure 2. *Foiling machine.*

2.1. The design and requisitioning of the table

To assess the feasibility of the new foiling machine, a thorough analysis of its structural integrity using the finite element method was conducted. The analysis was performed under different loading conditions, including the weight of several elevator doors and other potential loads [3].

In order to simplify the calculations, in this part of the study I have not shown the assembly to be presented later but during the verification, the load resulting from the weight of the specific kit as a distributed load was taken into account as a distributed load (**Figure 3**) **[3]**.

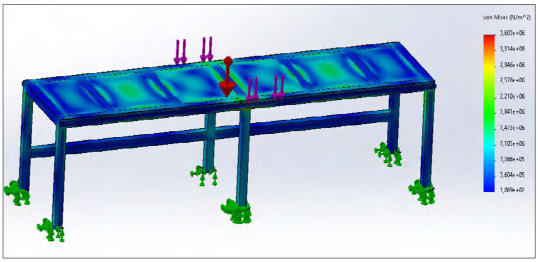

Figure 3. *Table load at idle.*

The analysis revealed that the rack is not overloaded even when both specific kits are located in the center of the rack, with a maximum tension of: 3.68 N/mm^2. Furthermore, as shown in **Figure 4** **[3]** the deflection of the structure barely reaches 0.1 mm.

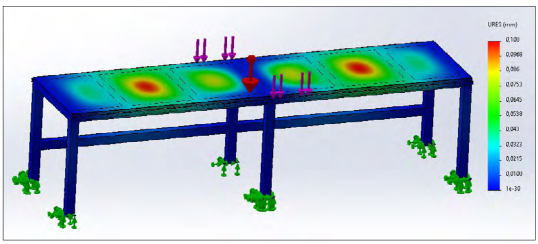

Figure 4. *Table deflection in idle.*

In examining the results (**Table 2**) it is notable that the average panel (**Figure 5**) **[3]**, has almost the same maximum compressive stress (4.26 N/mm^2) as the largest panel (4.27 N/mm^2) (**Figure 6**) **[3]**.

This may seem counterintuitive, but it is possible because the larger panel lies on a larger surface, and its weight can be distributed over a larger area, placing the load on more stiffening ribs, which in turn reduces the load on individual elements.

Additionally, when subjected to another load case where four 80-kilogram individuals sit on the structure (**Figure 7**) **[3]** the data shows that the structure is not critically loaded.

Table 2. *The stresses of the table in the case of different loads*

	Average elevator door	**The largest elevator door**
Pressure tension	4.27 N/mm^2	4.26 N/mm^2
Displacement / bending	0.18 mm	0.112 mm
	Load at idle	**In the case of other loads**
Pressure tension	3.68 N/mm^2	4.27 N/mm^2
Displacement / bending	0.108 mm	0.18 mm

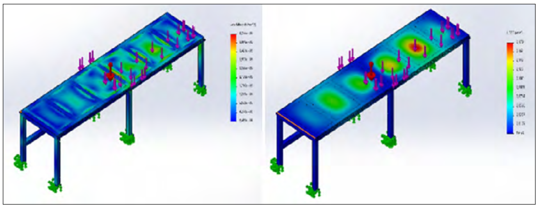

Figure 5. *For an average lift door load.*

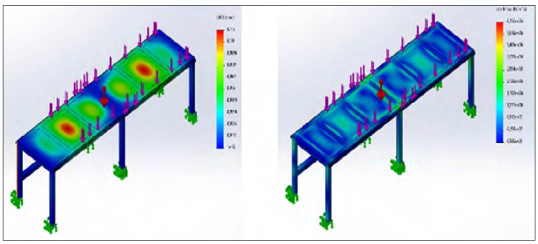

Figure 6. *For the largest lift door load.*

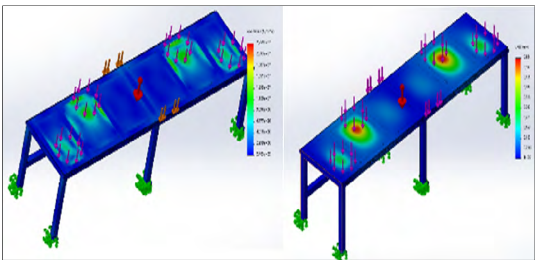

Figure 7. *In case of other loads.*

2.2. Specific kit design and loads

The specific kit's purpose is to guide and secure the foil, and it will also house the roller responsible for smoothing the foil (**Figure 8**) **[2]**.

The loads on the specific kit include its own weight, the foil roll support shaft, bushings, and bearings, as well as the weight of the foil roll and the force required to pull it down.

To determine the force needed to peel off the foil, a spring-loaded force meter was used at various pull-off angles. The force required was found to be 15 N, with a maximum force of 20 N. Therefore, the maximum force of 20 N when calculating the loads was accounted for.

The maximum compressive stress on the specific kit was 1.032 N/mm^2 (**Figure 9**) **[3]**. However, due to its dimensions, it is over-insured. In later versions, we will strive for weight reduction while maintaining its strength. Although the kit is relatively long, the largest deflection in the middle is still less than 0.01 mm (**Figure 10**) **[3]** which is within more than an acceptable range.

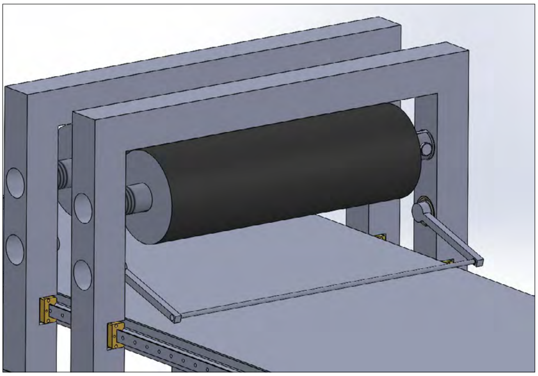

Figure 8. Specific kit.

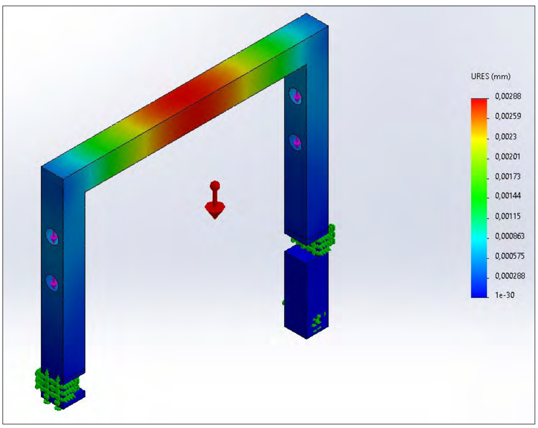

Figure 9. *Specific kit's bending Figure*

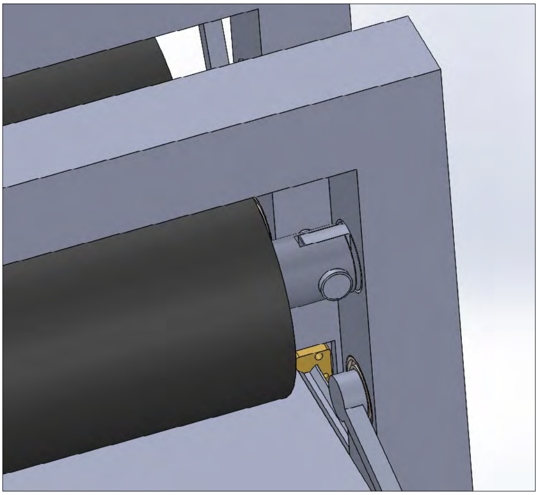

Figure 10. *Rotating shaft*

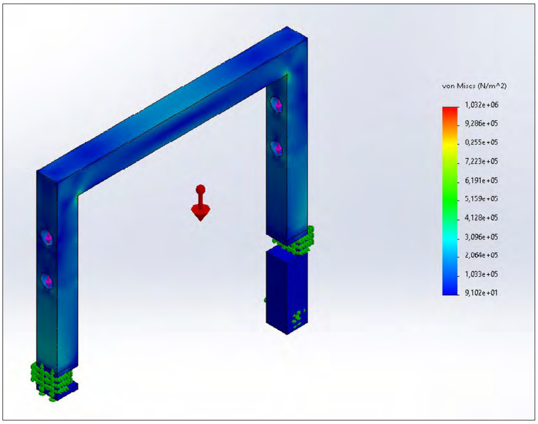

Figure 11. *Specific kit's pressure tension Figure*

2.3. Operation of the specific kit

The worker places the item to be foiled on the table, guides the foil under the smoothing roller, and threads it between the clamping jaws on the table. The operator then starts the machine, which unrolls the film from the roll by capturing it. The smoothing roller moves with the specific kit to smooth the foil. Once the covering is complete, the worker cuts the film that extends beyond the element and removes the element.

To increase productivity, two specific kits are placed on both sides of the machine, which move together. After foiling one element, the worker threads the foil on the other side and starts the specific kit in the other direction by pressing a button, foiling the next element.

To replace the coils, a rotating shaft was implemented (**Figure 11**) **[2]**. One end of the shaft is equipped with a joint that can be easily folded out to change the coils, and the other end has an easily removable clamping ring.

2.4. Specific kit inserts

The specific-kit-inserts are essential to facilitate the connection of the linear carriages to the specific kit. If the assembly consisted only of hollow sections, the carriage would only be able to rest on the wall thickness of the hollow section, which would not allow for safe and stable movement of the carriage.

The specific-kit-insert 02 (**Figure 12**) **[2]** will contain the necessary surfaces to grasp the ball nut. This part will be connected to the ball screw and ball nut, transferring the necessary movement for foiling. The specific-kit-insert 01 (**Figure 13**) **[2]** will assist in guiding the opposite side.

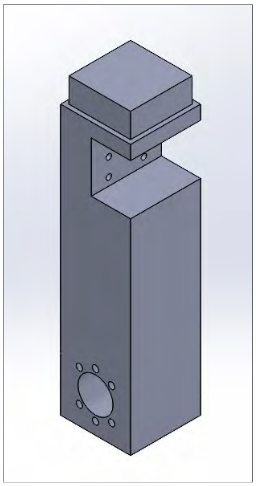

Figure 12. *Specific-kit-insert 02.*

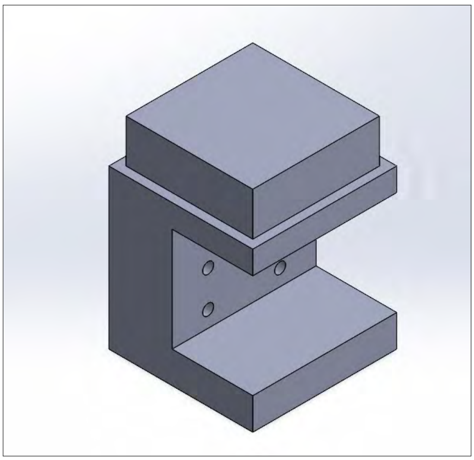

Figure 13. *Specific-kit-insert 01*

3. Dimensioning of linear line and linear carriage

The specific kit slides on the linear wire with the help of linear carriages. The linear carriages are fastened to the specific kit with 6 pcs M10 screws, thus ensuring a connection with adequate strength (**Figure 14**) [2].

The linear wire is loaded by the weight of the specific kit when idling, but during foiling, pulling off the foil also exerts some force on the linear wire (**Figure 15**) [2].

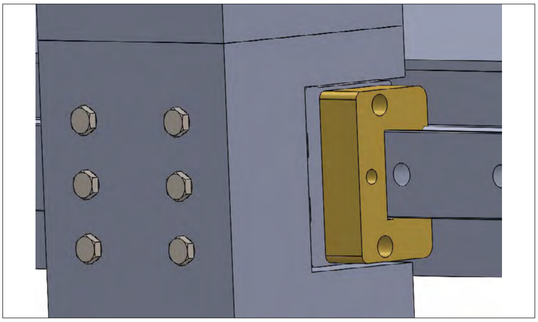

Figure 14. *Kit insert and linear carriage.*

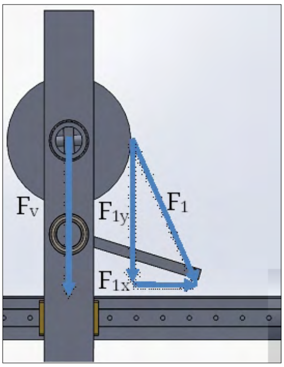

Figure 15. *Linear wire's load.*

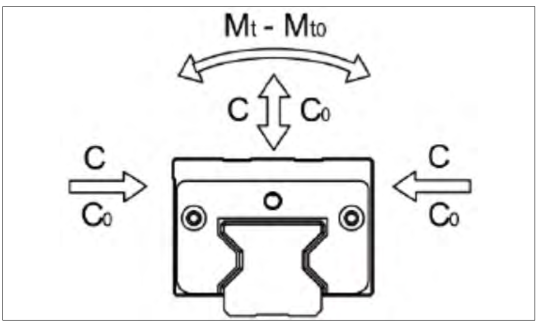

Figure 16. *Linear carriage's load capacities.* [4]

Maximum load of linear carriag:
$C_{max} = 53\ 000\,\text{N}$ [4]

$F_{1y} = F_1 \cdot \sin\alpha$
$\rightarrow F_{1y} = -20\,\text{N} \cdot \sin 20°$
$\rightarrow F_{1y} = 6.84\,\text{N}$

$C = (m_{kit} + m_{foil} + m_{other}) \cdot g \cdot F_{1y}$
$\rightarrow C = (42.5\text{ kg} + 7.5\text{ kg} + 5\text{ kg}) \cdot 9.81\text{ m/s}^2 \cdot 6.84\text{ N}$
$\rightarrow C = 546.39\text{ N}$

where:
C_{max}: linear carriage's load capacity
C: load
F_1: force required to peel off the foil
α: foil peel-off angle
m_{kit}: specific kit weight
m_{foil}: weight of foil roll
m_{other}: machine components and the weight of the smoothing roller
g: gravity acceleration

$C < C_{max} \rightarrow \text{C} = 546.39\text{ N} < C_{max}$

Ergo the chosen linear carriage is suitable.

4. Ball screw and ball nut sizing

A golyósorsót az elhanyagolható axiális terhelések miatt csak a kritikus fordulatszámra méretezem (katalógusadatok és képletek alapján).

$$n_{max} = f \cdot \frac{dr}{L^2} \cdot 10^7$$
$$\rightarrow n_{max} = 21{,}9 \cdot \frac{29{,}825mm}{4000mm^2} \cdot 10^7$$
$$\rightarrow n_{max} = 408\ \frac{1}{perc} = 6{,}8\ \frac{1}{s}$$

where:
n_{max}: maximum rpm
f: coefficient determined based on the mounting method of the ball screw
d_r: axle core gauge
L: mounting distance

The maximum speed, calculated with 32 mm pitch:

$$v_{max} = n_{max} \cdot P$$
$$\rightarrow v_{max} = 6{,}8\frac{1}{s} \cdot 32mm$$
$$\rightarrow v_{max} = 217{,}6\ \frac{mm}{s}$$

The required speed is the one at which the desired productivity is achieved. For this, the time required to wrap one element can be 15 s (t_{max}). To calculate the required speed, a 2200 mm (l) long door panel is used as a basis.

$$v = \frac{l}{t_{max}} \rightarrow v = \frac{2200\ mm}{15\ s} \rightarrow v = 146\ \frac{mm}{s}$$
$$v < v_{max} \rightarrow v = 146\ \frac{mm}{s} < v_{max}$$

Ergo the chosen ball screw is suitable.

5. Engine selection

To choose the appropriate motor, we first need to determine the maximum load force (Figure 7) [2]. This force is the sum of the friction force resulting from the weight of the specific kit and the force required to peel off the foil. Once we have calculated the load force, we can determine the required torque and choose a suitable motor. For this project, a stepper motor will be the best choice due to its torque retention and provision of additional automation options.

5.1. Determination of the forces and torque loading the motor

$F_v = (m_{kit} + m_{foil} + m_{other}) \cdot g$
$\rightarrow F_v = (42.5\ \text{kg} + 7.5\ \text{kg} + 5\ \text{kg}) \cdot 9.81\ \text{m/s}^2$
$\rightarrow F_v = 539.55\ \text{N}$

$F_s = F_v \cdot \mu \rightarrow F_s = 539.55\ \text{N} \cdot 0.2$
$\rightarrow F_s = 107.91\ \text{N}$

$F_{1x} = F_1 \cdot \cos\alpha \rightarrow F_{1x} = 20\ \text{N} \cdot \cos 20°$
$\rightarrow F_{1x} = 18.79\ \text{N}$

$F_t = F_s + F_{1x} \rightarrow F_t = 107.91\ \text{N} + 18.79\ \text{N}$
$\rightarrow F_t = 126.9\ \text{N}$

$M = \text{d}/2 \cdot F_t \rightarrow M = 0.032/2 \cdot 126.7\ \text{N}$
$\rightarrow M = 2.0272\ \text{Nm}$

where:

F_v: force due to the weight of towed elements
F_s: friction force
μ: sliding friction coefficient
F_t: load
M: torque
d: diameter of ball screw

Since it is necessary to move two kits, double this value must be taken.

Ergo: 2.0272 Nm · 2 = 4.054 Nm

Therefore, the following was chosen: NEMA 34 (6.6 Nm) [6](M_{max} = 6.6 Nm) type engine (Figure 18, 19).

6. Conclusions

During the verification of the design of the construction, after evaluating the finite element method, it was found that the structure is very over-dimensioned, so in the next period economical production/design will become the focus.

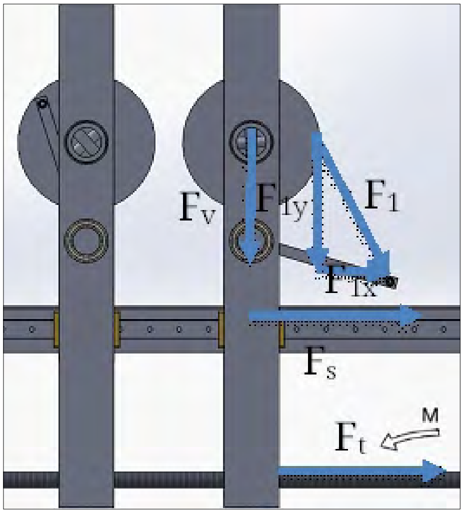

Figure 17. *Engine's loads.*

Figure 18. *NEMA 34 type motor*

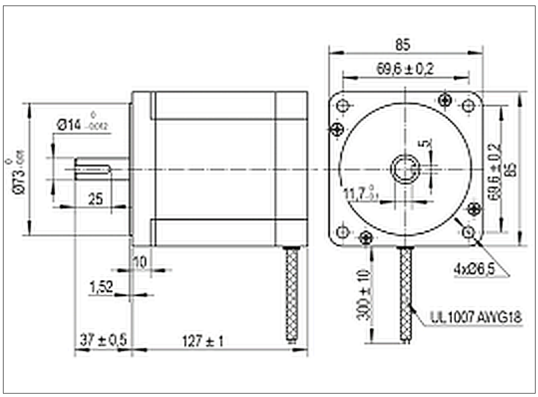

Figure 19. *A NEMA 34 type engine drawing* [6]

During the selection of the various sub-assemblies, such as the linear line or the linear carriage running on it, is found that an operator can operate these units with very low utilization, since the loading forces also assume low values. However, during further sizing, it was established that, for example, when determining the maximum speed and RPM, the ball screw and ball nut can be operated with almost maximum utilization, due to the large length.

In future, additional parts of the assembly, inserts and bushings, which are necessary for proper operation, must be designed. As well as the conditions for safe work, the machine must therefore be equipped with light gates, protection against contact and jamming, and protection against overload.

Furthermore, we selected full automation as a development direction. This means that, apart from the replacement of the foil roll and the one-time threading, all operations need to be automated. This requires an automatic cutting system so that the worker only has to do material handling. To cut the film, a cutting system and path must be planned and programmed. Therefore, we would like to introduce an easy-to-use, programmed PLC with a touch screen. With this, it is intended that the worker will be able to perform the foiling with a few touches, in the shortest possible time.

Alternative foiling methods are being investigated, a hot air blowing system has been formulated, with which we could also cover elements with more complex shapes and characteristics with a protective film. The system that provides this still needs to be developed and additional structural solutions have to be found.

Acknowledgements

Publication of this article was supported by the Scientific Council of University of Nyíregyháza.

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