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Design and Manufacturing of Pneumatic Driven Extension Spring Fatigue Machine

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ABSTRACT

In this study, a tension extension spring fatigue machine was designed and manufactured. This machine was designed to test extension springs for door mechanisms of the white appliances. The fatigue cycles were applied within desired strain while fatigue testing. The force applied by jaws was driven by pneumatic piston. The air pressure is 6 bar that acquired from local pneumatic network. The maximum force was designed to meet at least 12 kN. Thereby, multiple quantities of extension springs can be tested simultaneously. The applied force can be adjusted pneumatic air pressure adjuster. The fatigue cycles were controlled by an electronic circuit. The machine is also designed to complement desired number of fatigue cycles. For this reason, a counter was also added to controller. Manufacturing of the machine elements and its tolerances were also described in detail. After manufacturing, an exemplary pre-fatigue test was performed and its results were examined.

Pnömatik Tahrikli Çekme Yayı Yorulma Makinesi Tasarım ve İmalatı

MAKALE BİLGİSİ

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Anahtar Kelimeler:
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ÖZET

Bu çalışmada, bir çekme yayı yorulma makinesi tasarlanmış ve imal edilmiştir. Çekme yayı yorulma makinesi beyaz eşya kapı mekanizmalarında kullanılan çekme yaylarını test etmek için tasarlanmıştır. Yorulma testi yapılırken yorulma döngüleri arzu edilen gerinim ile uygulanabilmektedir. Çeneler tarafından uygulanan kuvvet, pnömatik piston tarafından tahrik edilmiştir. Hava basıncı 6 bar olarak yerel pnömatik şebekeden sağlanmıştır. Çenelerin uygulayabildiği en yüksek kuvvet en az 12 kN'yi karşılayacak şekilde tasarlanmıştır. Böylece birden çok sayıdaki uzatma yayı aynı anda test edilebilmektedir. Ayrıca, uygulanan kuvvet pnömatik hava basıncı ayarlayıcı ile ayarlanabilmektedir. Yorulma döngüleri bir elektronik devre tarafından kontrol edilmektedir. Makine istenen sayıda yorulma döngüsünü tamamlayacak şekilde tasarlanmıştır. Bu nedenle, denetleyiciye yorulma döngüsünü ölçen bir sayaç eklenmiştir. Makine elemanlarının imalatı ve toleransları da detaylı olarak anlatılmıştır. İmalat sonrasında, örnek bir ön yorulma testi yapılmış ve sonuçları irdelenmiştir.

1. INTRODUCTION (GİRİŞ)

Springs are of important elements of the machinery designs since they store mechanical energy to potential energy. The springs work as a transformer between kinetic and potential energy. The potential energy is released back to kinetic energy depending on machine or design structure [1]. Thereby, the springs are used not only for energy storage but also for vibration damping. Vibration is one of the main source of fatigue [2]. Fatigue is a failure resulting from cyclic behavior of the

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load [3, 4]. Cracks are formed and propagated through, resulting in failure of the machine elements [5, 6].

The springs store the energy by some behavior such as compress and extension [7, 8]. The wire of the spring is twisted while spring compressed or extended [9]. The cyclic compression and extension of the spring results in cyclic twisting. Therefore, the springs are also vulnerable to the fatigue much as a standard machine element [10-12].

The springs are designed to store maximum capacity of energy by increasing area under the tensile strength curve [13]. As the tensile strength and elongation at break rises, the capability to store energy also increases [14]. However, high tensile strength with increased hardness of the steel rises sensitivity to the crack formation and propagation [15]. For this reason, the springs are susceptible to the fatigue failures.

There are studies regarding fatigue life of the springs in the literature. Several studies have followed some standard for testing procedures or manufactured tailor made testing devices. Kumar et al. [16] tested leaf and coil springs made of EN47 steel which is widely employed landing gears. They followed ASTM E606 standard for low cycle fatigue testing. A strain controlled fatigue analysis machine was employed for fatigue tests. They used strain rate of 0.3% and 0.3Hz as fatigue speed. Zhang [17] et al. studied effect of fatigue life on twins torsion spring made of 07Cr17Ni7Al stainless steel. They used 5-mm amplitude and fatigue test speed of 5 Hz. They used a reciprocating-type fatigue testing machine for twins torsion spring. Hashemi et al. [18] studied fatigue life helical spring made of shape memory alloy. The experiments were conducted with 0.2 and 0.123 s^{-1} strain rates. To sum up, there is some standards regarding fatigue testing but there are special testing procedures for special purpose springs.

A fatigue life of the spring is important to determine since failure of the spring can results in serious accidents. In this work, a machine for fatigue life of an extensions spring designed for home appliance doors were designed and manufactured. The details of the design and manufacturing were discussed in detail. The testing procedure and machine design were planned according to ISO 22705-2 standard. ISO/DIS 22705-2 is suitable for this work and describes the standard test procedures for extension springs [19].

2. MODELLING AND DESIGN (MODELLEME VE TASARIM)

2.1. Extension Spring Design for Fatigue Tests (Yorulma Testleri İçin Çekme Yayı Tasarımı)

The force loss against fatigue cycle is determining factor for fatigue life. After desired fatigue cycle, the force loss is expected to be minimum. ISO/DIS 22705-2 was employed for a reference to measure fatigue life of the spring. According to the ISO/DIS 22705-2, there is no obligation regarding measurement of spring force. Fatigue test can be applied without measure the spring force. For this machine, force was not measured and only strain that applied by pre-extending spring length can be adjusted. The force loss is measured by between some testing intervals taking outside of the machine.

The fatigue machine was designed to test with quantity of ten extension springs. This quantity of testing specimen increases the reliance on results. This capacity is also depend on the force obtained from pneumatic cylinder.

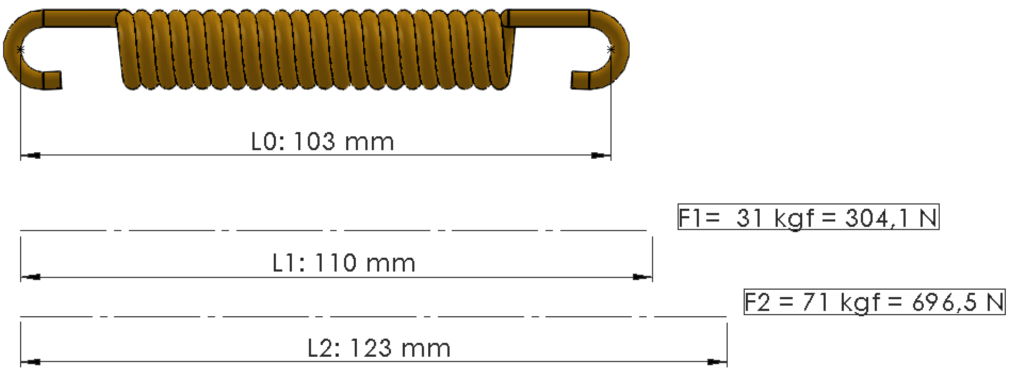

Figure 1. Calculated forces for different extensions

Extension fatigue machine design is based on springs for home appliance door. The size of the extension spring has an important effect on machine design. Figure 1 shows a basic drawing and some calculations of an extension spring. Here, L0 is natural length, L1 is first length for working of extension spring, L2 is maximum length of the extension spring.

The forces are calculated according to (1). The drawing forces also confirmed by measuring with a load cell.

$$F = k \cdot x \tag{1}$$

Here, F is Force (kgf), k is spring coefficient (kgf mm^{-1}) and x is the extension length (mm). It should be noted that there is a base force before extend an extension spring to overcome. This force is affected from Young modulus, diameter of the wire, pitch and wrapping diameter. K is determined by following equation by measuring forces and the length of the extension.

$$k = \frac{\Delta F}{\Delta x} = \frac{F_2 - F_1}{x_2 - x_1} = \frac{71-31}{123-110} = 3.08\ kgf \cdot mm^{-1} \tag{2}$$

The base force to overcome before extend the extension spring is determined as 3.08 $kgf \cdot mm^{-1}$. Based on this result, the base force is determined as approximately 9.4 kgf by eq. (3) and eq. (3).

$$F_1 = F_{base} + (L1 - L0) \cdot k \tag{4}$$

$31 = F_{base} + (110 - 103) \cdot 3.08$

$F_{base} = 31 - 21.5$ kgf

$F_{base} = 9.5$ kgf

$$F_2 = F_{base} + (L2 - L0) \cdot k \tag{5}$$

$71 = F_{base} + (123 - 103) \cdot 3.08$

$F_{base} = 71 - 61.6$ kgf

$F_{base} = 9.4$ kgf

Total force (F_{Total}) is obtained by eq. (4) 6965 N for 10 extension spring.

$$F_{Total} = n \cdot F \cdot g \tag{6}$$

$$F_{Total} = 10 \cdot 71 \cdot 9.81$$

$$F_{Total} = 6965\ N$$

2.2. Diameter of the pneumatic piston (Pnömatik Pistonun Çapı)

Driving force that extend the springs should be sufficient to complement the fatigue cycle. The diameter of the driving piston should be calculated to generate force yield. The diameter of the cross section is directly proportional to the driving force. Also, air pressure has an influence on the driving force. However, pneumatic air pressure regarded constant (6±0.5 bar). The diameter of the pneumatic cylinder is selected as 160-mm. The pneumatic cylinder was selected as double acting type. Since there is no returning spring inside, a spring that undergo fatigue cycles is prevented. Thereby, machine working life is increased. As for calculation of the pneumatic spring diameter, the working diameter is expected to greater than applied force.

$$6 \text{ bar} = 600000 \text{ Pa} \quad (7)$$

$$A = \prod \text{ x } r^2 = \prod \text{ x } 0.08^2 = 0{,}0201 \text{ m}^2 \quad (8)$$

$$F_{Cylinder} = P \text{ x } A = 600000 \text{ x } 0.0201 = 12060 \text{ N} \quad (9)$$

The cylinder application force is obtained as 12060 N that is greater than the force for sum of the ten extension spring, namely, 6965N. Therefore, generated force for designed cylinder is easily sufficient for the fatigue machine.

2.3. Design of Fatigue Machine (Yorulma Makinesi Tasarımı)

The machine design consists of 13 parts. The part names and material types or brands are given in Table 1.

Table 1. Designed parts for fatigue machine (Yorulma makinesi için tasarlanan parçalar)

No	Part name	Part name or Material	Quantity
1	Pneumatic cylinder	Pemaks PKD-A 160 - 50	1
2	Upper plate	1050 Steel	1
3	Column support	1050 Steel	2
4	Linear guide	HIWIN HG20	2
5	Upper spring holder	1050 Steel	1
6	Lower spring holder	1050 Steel	1
7	Guide	HIWIN HGR20C	2
8	Lower plate	1050 Steel	1
9	Spring holder pin	CTPh7. 6 x 20	20
10	Spring holder fixer	1050 Steel	2
11	Cylinder adapter tip	1050 Steel	1
12	F1 distance adjuster	1050 Steel	1
13	F2 distance adjuster	1050 Steel	1

The fatigue machine design is shown in Figure 2a-c. Accordingly, the pneumatic drive cylinder (1) is fixed on the upper table (2) and the columns (3) with bolts. Ball bearing rail (7) is mounted on the column support body (3) in order to provide linear movement capability. Rail carriage (4) and tensioner undercarriage plate (6) are mounted on the rail (7). Thereby, it has become possible to adjust the length by tightening it with a T bolt (11) and nut to allow springs of different lengths to be attached to the machine as seen.

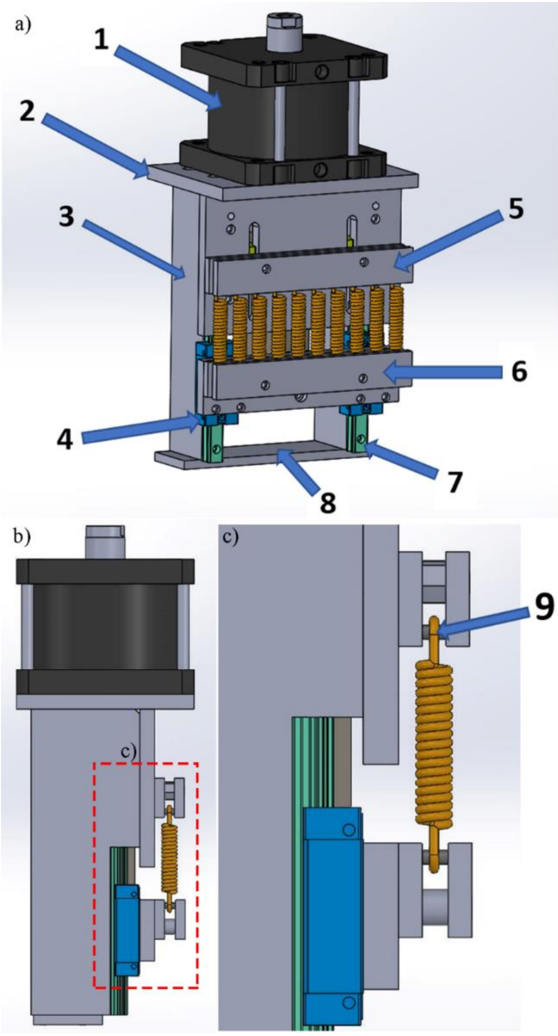

Figure 2. Machine design views from a) Isometric perspective, b) Left and c) Partial detail from the left view
(a) izometrik perspektiften, b) soldan ve c) soldan kısmi detaydan makine tasarım görünümleri)

Fatigue machine design from back side and a detail view is shown in Figure 2a and 2b, respectively. F1 and F2 distance adjuster is consists of two block that works with each other to stop the movement. As the position of the blocks can be adjusted. The brown block for F2 positioner (13) is mounted to lower plate and can be adjustable. Therefore, extension springs with various lengths can be tested.

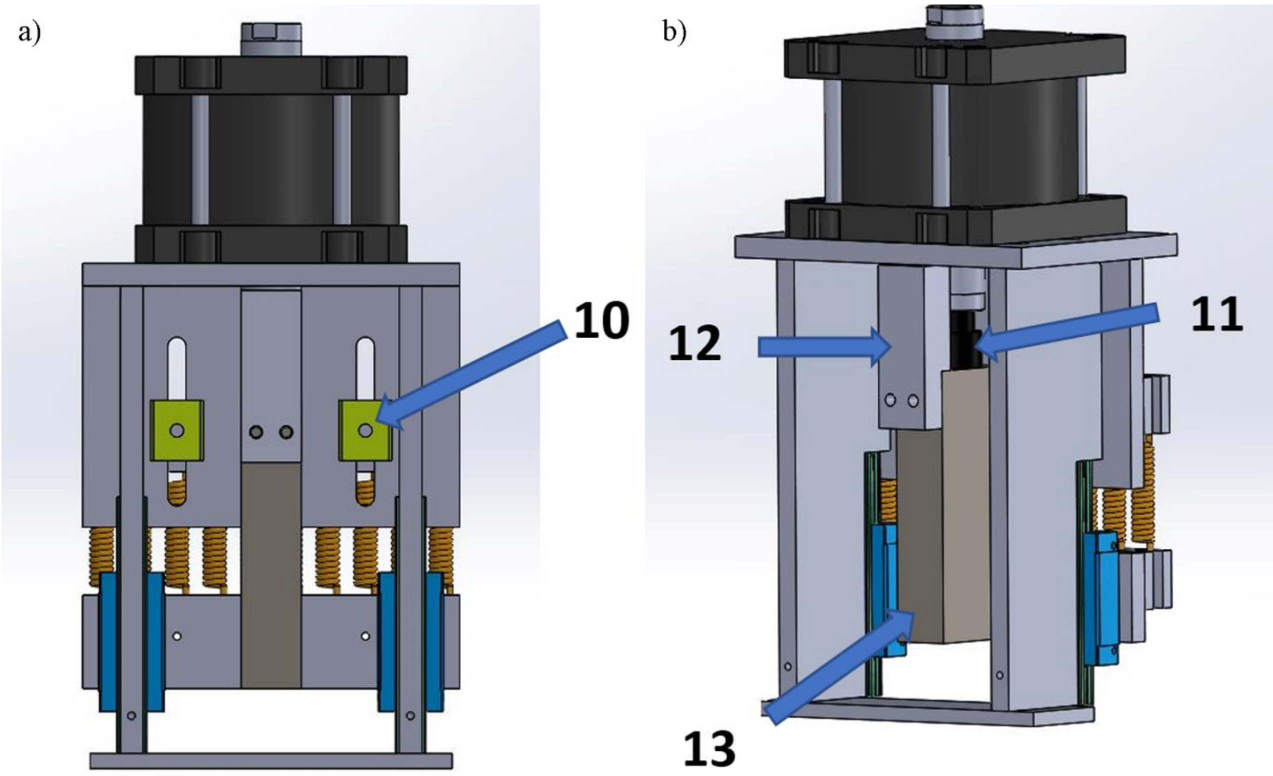

Figure 3. Design of fatigue machine from a) back side and b) a detail view (Yorulma makinesinin a) arka tarafından tasarımı ve b) detay görünümü)

2.4. Working Principle and Electrical Circuits **(Çalışma Prensibi ve Elektrik Devreleri)**

Scheme of power supply and control circuit for extension spring fatigue machine is shown in Figure 4a and 4b, respectively. The machine works with 220V main network current. The equipment names or brands are given in Table 2. Main current directly feeds 24V PSU and digital counter. To protect the machine from overcurrent, an electric fuse with 1A limit was placed before feeding the machine. A switch relay was also embedded before relay to control the feeding current.

Table 2. List of equipment used in the fatigue machine (Yorulma makinesinde kullanılan ekipmanların listesi)

No	Name of equipments	Quantity
1	5/2 24V Double Coil Valve	1
2	MCB-9 multiple function timing relay	1
3	24V Relay	1
4	24V power supply	1
5	2 Amper safety relay	1
6	Emergency stop button	1
7	ECH7700 Counter	1
8	RZT1 Sensor	1

As for the control circuit, piston sensor triggers R1 relay on every opening via NPN 24V piston sensor. R1 relay undertakes a pulse role for ENDA ECH7700 digital counter. MCB9 is a timing relay. The timing relay also controls the speed of the fatigue cycle. The timing relay is adjusted to 2 Hz speed, namely, 2 cycle per second. If the timing relay, R1 relay, Emergency stop and ECH7700 counter is on the opened mode, the P1 solenoid valve is opened.

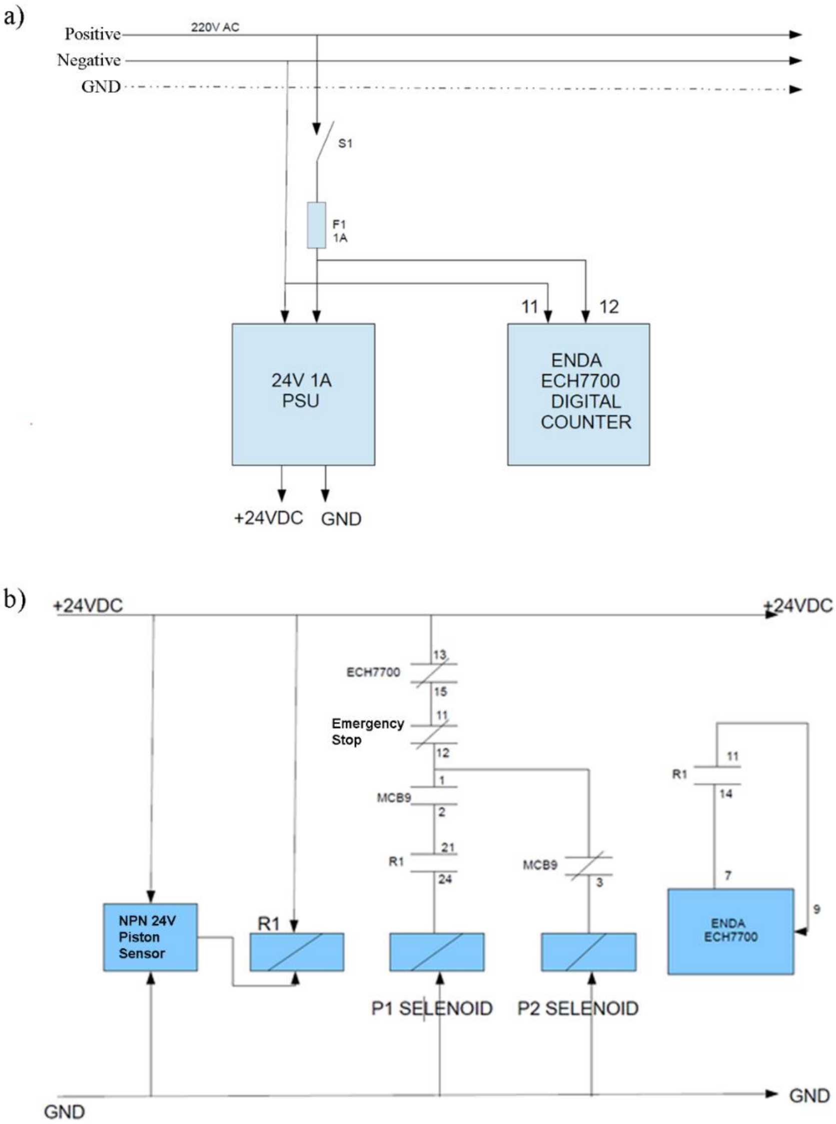

Figure 4. Scheme of a) power supply and b) control circuit for extension spring fatigue machine (Uzatma yayı yorulma makinesi için a) güç kaynağı ve b) kontrol devresi şeması)

P2 solenoid is designed for returning of the cylinder to the first state of the cycle. The conditions for P2 solenoid are same as the P1 except for MCB9. If MCB9 timing relay is off, enfolding of the cylinder is works. It cannot be expected to turn off cylinder when timing relay pulses as open since the opened state is works only for turn on the cylinder.

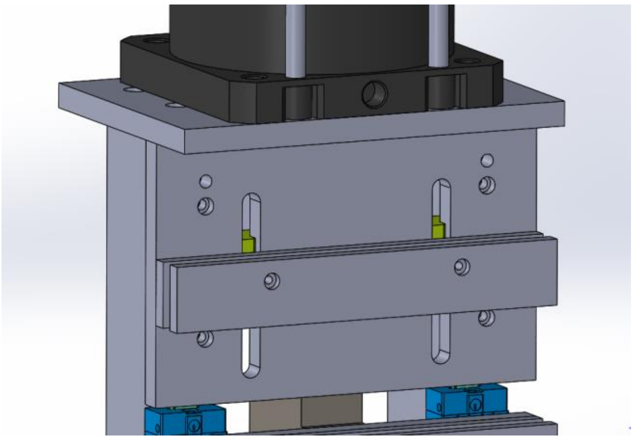

Figure 5. Adjustable head plate design for different length of extension springs (Farklı uzunluktaki uzatma yayları için ayarlanabilir başlık plakası tasarımı)

Before the springs are connected to the test device, the upper connection part number 5 of the test device is moved and fixed according to the operating range of the springs. Figure 5 shows this adjustable plate of the upper jaw. Then, the springs are attached to the pins and the device is powered. Pneumatic piston rod pushes the part number of 13 down the springs to the end of the L2 working length. In this position, part 12 is connected to part 13 with bolts. Figure 6 shows image of the extension spring fatigue machine in L1 and L2 position. When the pneumatic piston is retracted, the device returns to the L1 position with the forces stored in the springs and the system is operated in the range L1 -L2 for the desired cycle as a cycle.

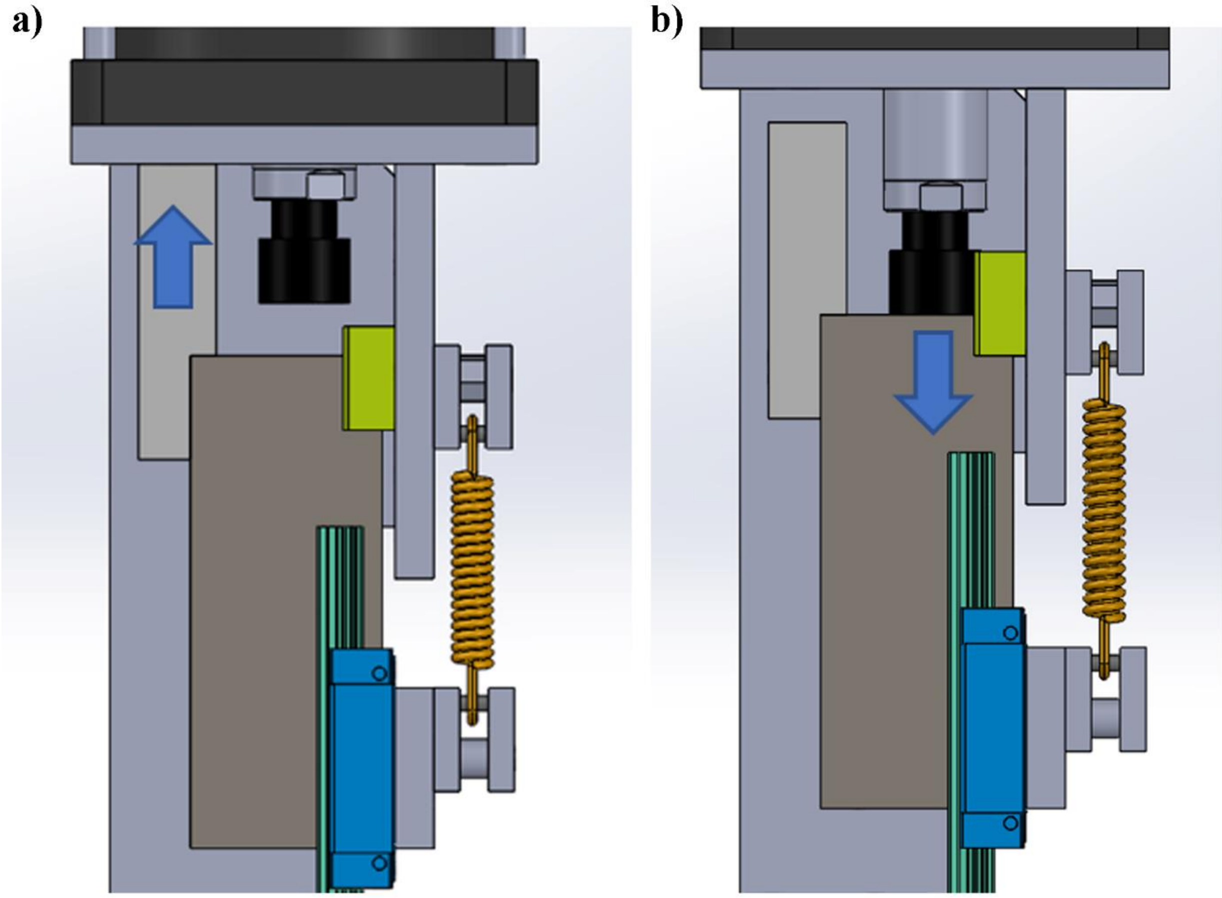

Figure 6. The image of the extension spring fatigue machine in a) L1 position and b) L2 position (Uzatma yayı yorulma makinesinin a) L1 konumunda ve b) L2 konumunda görüntüsü)

2.4. Manufacturing of the Fatigue Machine (Yorulma Makinesi İmalatı)

Figure 7 illustrates extension spring fatigue machined as manufactured and mounted state. The fatigue machine plates were produced from ck45 steel. The edges are milled and positioning tolerance was adjusted to ±0.05 mm. The wide surfaces that work with rail and rail carriages are grinded. The surface roughness (Ra) for these surfaces was 3.2 µm. No heat treatment was applied to these plates. For accurate positioning and mounting of position pins, hole tolerances were used as h7. Reamers for h7 were employed after drilling of the holes. 0.1 mm chip thickness was allowed for reaming process. Allen bolts were used. 10.9 quality used for the bolts to prevent deflection, fatigue and antiblockage of the bolts.

Figure 7. The extension spring fatigue machine after manufacturing and mounting (İmalat ve montajdan sonra uzatma yayı yorulma makinesi)

2.4. Early Fatigue Tests (Ön Yorulma Testleri)

Figure 8.a and 8.b shows spring force results for 10% and 22% elongation, respectively. The spring forces were measured before and after 20 000 cycle of fatigue. According to the results, there was a limited decrease for both elongation. There was only 0.6 N and 0.8 N force loss for 10% and 23% elongations, respectively. Already, an important force loss is to be expected start from 50 000 cycle, these measured losses can be expected. However, fatigue tests have decreased the spring force even it was low amount.

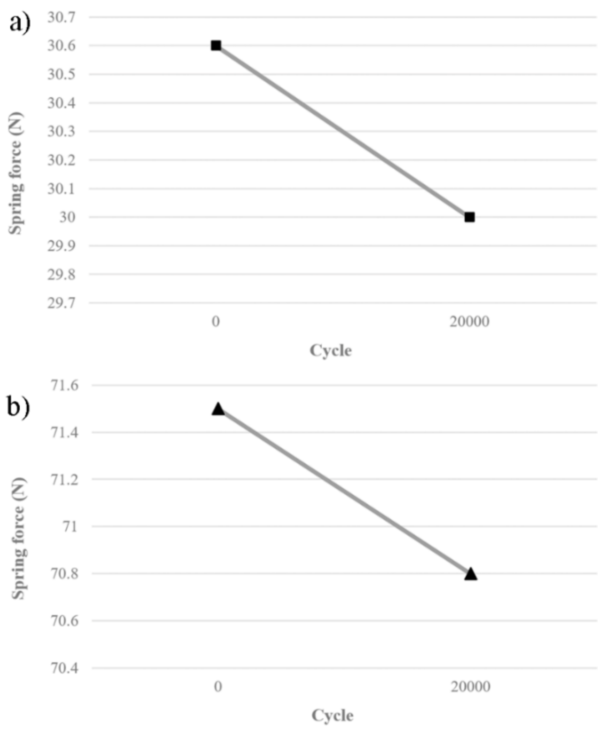

Figure 8. Spring force results after a) 0 cycle and b) 20 000 cycle (a) 0 döngü ve b) 20 000 döngüden sonra yay kuvveti sonuçları)

3. CONCLUSIONS (SONUÇLAR)

In this study, a machine was designed and manufactured to determine the fatigue life of extension springs of different sizes. The extension spring fatigue machine is designed to determine the fatigue life of door springs in consumer durables. In the study, necessary calculations were made for the required forces. A 120-mm diameter pneumatic cylinder was selected under 10 extension springs and a standard 6-bar operating pressure. Producing a total force of 12060 N, this cylinder is double that of a standard door extension spring. The electrical diagram and the working principle with pneumatic control are explained in detail. The highest fatigue cycle rate obtained was determined as 2 Hz. This speed will give the most suitable results as it mimics the real fatigue speed. Early tests applied to the specimens at 0 and 20 000 cycle illustrates there is a force loss for extension springs although it was limited.

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