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RESEARCH ARTICLE OPEN ACCESS

DısableStaırLıftDesıgnWıthLınear Motor

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ABSTRACT
Disable Lift
Disable Stair Lift
Linear Motor
Tubular Linear Motors
Nowadays, linearmotorsareused in manyareas, such as maglevtrains, medicaldevices, defenseindustry, textilesector, sensitiveproductionprocesses. As theareas of usage is rising, theircoverage in R&D activitiesandacademicstudieshavebeengraduallyincreased as well, duetohighrelevanceformassproduction, abilitytoobtainfastermovement, precisionandhavinghighqualityoutputs/productscomparedtoother engine andpowergeneratingsystems. Inthisstudywill be mentionedaboutstructures of linear motor anddisable lift andwillprovethepossibility of thedesign of disablestair lift withlinear motor, whichthedesign is not usedorsubjected of anyotherthesisduetostructure of thelinear motor.

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I. INTRODUCTION

Duetoabilityofsensibleandfastmovement of linearmotors, theusage is increasingdaytoday in theworld in most of industries. Thisstudypresents a theoraticalstudy on disablestair lift designwithMaglevTechnology, which has recentlystartedto be applied on elevators.

Kazan (2009), “DesıgnAndImplementation Of A Linear MotorFor Multi-Car Elevators” Inthisthesis,newcomponentsforlinearmotormulti-carelevatorshavebeenanalysedandexperimentedsuccessfully.

Cepni (2010), “LinearServo Motor AndIts Control” Workingprinciplesofexistinglinearmotors,application areasoflinearmotor Technologies areprimarilymentionedandthenadvantagesofthelinear motorsystemsaccordingtotheotherlinearmotionsystemsarediscussed in thestudy.

Topaloğlu(2012),“DesignOfLinearElectromagneticLauncherSystem”Inthisstudy,singlesidelinearinduction motorhasbeendesignedtouseinanelectromagneticlaunchersystemthatwouldbealternativeofmechanicallauncher systemforunmannedaerialvehicle.

Karayagiz (2013), “Network opologıesForLongArmatureLinearMotors” Inthisthesis, can protocolthat is a reliablereal-time communicationprotocolforcontrolsystems is usedandtwodifferent network topologiesentitled as topologyAandtopologyBareintroducedforthecommunication of motor drivers of long armatüre linear motor.

Taskin (2015), “Design AndImplementation Of A Double-SidedCorelessLinearMotor” Thisthesisdescribesallthestepstodesign a corelessdouble-sidedlinear motor byusingthe software ANSYS-Maxwell. Thegoal is todesign a doublesidedcorelesslinearmotortogetabetterforcecharacteristicswithprecisecontrol, thencomparethetests of thedesignwiththesimulationresults.

Tuncay (2016), “The Design And Control Of PermanentMagnet DCLinear Motor” Inthisstudy, a double-sidedpermanentmagnet DC linear motor has beendesigned. Themostsignificantadvantages of thelinearmotorarethatitsmagneticcircuitissimpleandits drivingcircuitsarenotcomplicated.Itsthrust/currentratio,whichisfundamentalperformancecriteriaoflinearmotors, is twicehigherthanexistingmotors.

Bozbuga (2018), “A NovalConceptual DesignOfAStairliftForElderlyAndDisabledPeople”Thisthesiscontainsaresearchaimedat'DevelopingaStairlift fortheElderlyandtheDisabled'.Theelevatorsystemssimilartothoseusedinthisstudyareproducedindevelopedan dindustrializedcountries, but this is an issueforourcountry.

II. LINEAR MOTOR

Linear motors, in other words linear inductance motors, are asynchronous motors operating with alternating current (AC). The operating principles are the same as inductance motors and consist of rotor and stators [1]. Based on the type of linear motor it, the parts on rotor and stator may vary from natural magnet to electro magnet [2].

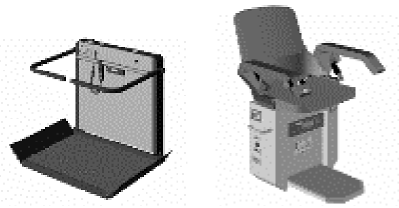
In Turkey, various studies have beenconducted on linear motors. There is also a study carried out by Dr Ahmet Onatat Sabancı University, in this regard. There is a lift driven by a linear motor.

Figure 2.1 Test drive conducted by Sabancı University for a linear motor driven elevator [3].

III. DISABLED LIFT

The lift types, which are designed for the use of people who are trying to climb a staircase but cannot (old or disabled), are called the disabled lifts. Disabled lifts are used to make it possible for people who want to overcome altitude or obstacles, obstacles easily, without needing anyone else. It provides comfort and mobility to the disabled person.

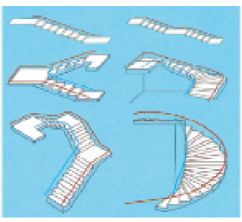
In home lifts, design and production are carried out for two purposes.



In Figure 3.1 Disabled Stair Lifts with Platform and Seat [4].

3.1 Application Areas

Thanks to the ease of production and competition of many international companies in this sector, disabled lifts developing technology is used in all types and design stairways. Figure 3.2 shows several different types of stairway details.



In the Figure 3.2 Application areas for disabled lifts [4].

IV. LINEAR MOTORIZED STAIR LIFT DESIGN

4.1 Determination of Design Objectives

In linear motor design, we can divide the design stages into 3 phases [5];

1. Pre-design Phase;
2. Design Phase;
3. Post-Design Correction;

Generally, determination of the pre-design targets can be listed as marketing activities, market analysis, target market determination, annual production targets, determination of customer needs, product characteristics, price and design time determination and release date.

The objectives regarding the disabled motor design with linear motor to be designed should be evaluated at the pre-design stage. These evaluations can be done by examining the superior and deficient aspects of the products of the competing companies such as reverse engineering method.

The main pre-design objectives of the design of the linear motorized disabled before design are as follows;

- Carrying mass: 300kg,
- Angle of stair: 67^{o},
- Height of stair: 3m,
- Average speed, which isnot affecting human comfort, should be between 0.05 m/s and 0.15 m/s,
- Safety risk, safe transportation of passengers, compliance with relevant regulations,
- The lifespan of the elevator: 10 years,
- Target of maintenance cost per year: 1000TL,
- Silent operation for human comfort,
- As the lift will work inside the building, no resistance against moisture and water,
- Due to the fact thatlift is going to work on a stairway, engine must take up as little space as possible.

The auxiliary targets of the linear motorized elevator are:

- It should be ergonomically suitable for human comfort,
- The product must be suitable in terms of aesthetics,
- It should be easy to use,
- It should be easy to manufacture and assemble,
- Manual control should be easy and clear.

According to main and auxiliary objectives, lift will be driven with tubular type linear motor. The power and force to be produced by the tubular shaped linear motor will be higher and tubular shaped linear motor will take a small place also.

4.2 Designing

4.2.1 Calculation of desired velocity and acceleration values

Although the minimum operating speed of normal human lifts is 1m/s, for this type of stairway lift, the speed of 1m/s will be disturbingly fast and uncomfortable. Therefore, as stated in the catalogs of existing manufacturers, for a comfortable, smooth stair lift, speed should be between 0.05 and 0.15 m/s.

The speed we will use in this example has been decided as;

$$V = \frac{0,05+0,15}{2} = 0,1 \text{ m/s} \quad (1)$$

Although the climbing angle of this type of stair lifts is maximum 45^o, in terms of design, in our country it is determined as 67^o.

Despite the fact thatthe loading capacity in the catalogs of the current manufacturers is generally 1250N, loading capacity is determined as 1500 N in this design, the total mass to be transported is determined as 3000 N considering the equipment weight.

Since the average height of the buildings in Turkey is 3m from floor to floor, same measure is chosen for this design.

M: Load Capacity (N) + Equipment Weight (N) = 3000 N

Q: Stair Angle (Climbing Angle) = 0 – 67 ^{0}

V: Speed (m/s) = 0,1 m/s

y: Floor Height (m) = 3 m

x_1: Floor Height (m) = 1 m

x_2= y / sin Φ (m) = 3 / sin 67 = 3,26 m

x_3: Horizontal Distance After Incline (m)= 1 m

To find out acceleration and speed;

V_1: Takeoff Speed (m/s) = 0 m/s;

V_2: Last speed before slope (m/s) = 0,10 m/s;

V_3: Speed after Slope (m/s) = 0,10 m/s;

V_4: If Stopping Speed (m/s) = 0 m/s;

Time for x_1, x_2 and x_3 ;

$$t_1 = \frac{X1}{2(V2-V1)} = \frac{1}{2 \text{ x } (0,1-0)} = 20 \text{ s} \quad (2)$$

$$t_2 = \frac{X2}{V3} = \frac{3,26}{0,1} = 32,6 \text{ s} \quad (3)$$

$$t_3 = \frac{X3}{2(V3-V4)} = \frac{1}{2 \text{ x } (0,1-0)} = 20 \text{ s} \quad (4)$$

For acceleration values;

$$a_1 = \frac{V2-V1}{t1} = \frac{0,1}{20} = 0,005 \text{ m/ s}^2 \quad (5)$$

$$a_2 = \frac{V3-V2}{t2} = \frac{0}{32,6} = 0 \text{ m/ s}^2 \quad (6)$$

$$a_3 = \frac{V4-V3}{t3} = -\frac{0,1}{20} = -0,005 \text{ m/ s}^2 \quad (7)$$

The movement of the lift is divided into 3 parts. First case acceleration, the second case is the constant speed and the third is the deceleration.

4.2.2 Calculation of the Power to be Produced by the Linear Motor

For both conditions of acceleration - constant speed - deceleration, we will have different power consumption.

In the first case, finding Fx_{max1};

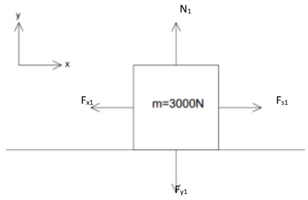


Figure 4.1 The first case, directions of the forces.

g = Gravity Acceleration = 9,81 m/ s^2

$$\sum F_{y1} = 0 \quad (8)$$

$$\sum F_{y1} = m.g - N_1.k_k \quad (9)$$

$$N_1 = m.g \quad (10)$$

N_1 = 300. 9,81 = 2943 N

k_k= coefficient of friction was selected as= 0.3

$$\sum F_{x1} = m.a_1 - (-N_1 . k_k) \quad (11)$$

F_{x1} = 300 . 0,005 + 2943 . 0,3 = 884,4 N .

In the second case, finding Fx_{max2} ;

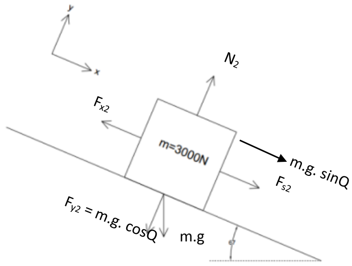


Figure 4.2 The second case, directions of the forces.

$$\sum F_{y2} = 0$$

$$\sum F_{y2} = m.g.\cos Q - N_2$$

N_2 = m.g.cosQ

N_2 = 300 . 9,81 . cos67^o= 1149,83 N

$$\sum F_{x2} = m.a_2 + m.g.\sin Q - (-N_2 . k_k)$$

Fx_2 = 300 . 0 + 300 . 9,81 . sin67^o + 1149,83 . 0,3 = 3053,97 N.

Finding Fx_{max3} in the third case;

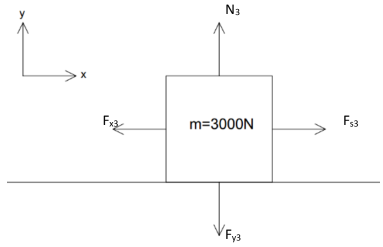


Figure 4.3 The figure showing the directions of the forces in the third case.

$$\sum F_{y3} = 0$$

$$\sum F_{y3} = m.g - N_3$$

N_3 = m.g

N_3 = 300 . 9,81 = 2943 N

$$\sum F_{x3} = m.a_3 - (-N_3 . k_k)$$

F_{x3} = - 300 . 0,005 + 2943 . 0,3 = 881,4 N.

In order to find F_{ort};

$$F_{ort} = \sqrt{\frac{F_1^{\,2}.t_1 + F_2^{\,2}.t_2 + F_3^{\,2}.t_3}{t_1+t_2+t_3}} \quad (12)$$

$$F_{ort} = \sqrt{\frac{884{,}4^2.20 + 3053{,}97^2.32{,}6 + 881{,}1^2.20}{72{,}6}} = 2148{,}84 \text{ N}$$

Since work is the force spent along a road,

$$W_{ort} = F_{ort}.x_t \quad (13)$$

$$W_{ort} = 2148{,}84.5{,}26 = 11302{,}9 \text{ J}$$

Again, from the formula (13), the work calculation for each case is found as[6];

$$W_i = F_i.x_i$$

$$W_1 = 884{,}4.1 = 884{,}4 \text{ J}$$

$$W_2 = 3053{,}97.3{,}26 = 9955{,}94 \text{ J}$$

$$W_3 = 881{,}4.1 = 881{,}4 \text{ J} .$$

For the power measurement,

$$P_{ort} = \frac{W_{ort}}{t_t} \quad (14)$$

$$P_{ort} = \frac{11302{,}9}{72{,}6} = 115{,}68 \text{ W}$$

Again, from the formula (14), the work calculation for each case is found as[6];

$$P_i = \frac{W_i}{t_i}$$

$$P_1 = \frac{884{,}4}{20} = 44{,}22 \text{ W} \qquad P_2 = \frac{9955{,}94}{32{,}6} = 305{,}39 \text{ W}$$

$$P_3 = \frac{881{,}4}{20} = 44{,}07 \text{ W}$$

3.2.3 Linear Motor Power Calculation

V_{DC} : Supplied Voltage = 220 V

I : Current (A)

R_{rail}: Resistance (Ω)

$E_{Induced}$: Induced voltage (V)

$$V_{DC} = I.R_{rail} + E_{induced} \quad (15)$$

$$E_{induced} = B.L.u \quad (16)$$

L: Effective length = Since number of windings x Winding length (m)

$$P_{in} = V_{DC}.I \quad (17)$$

$$P_{out} = E_{induced}.I \quad (18)$$

$$\mu = \frac{P_{out}}{P_{in}} \quad (19)$$

$P_2 = 305{,}39$ W in terms of safety;

$P_{out} = 400$ W

μ = 0,92

If values are placed in the formula (19) [6];

$$P_{in} = \frac{P_{out}}{\mu} = \frac{400}{0{,}92} = 434{,}78\ W$$

If the formula (17) is used to find the desired stream [6];

$I = \frac{P_{in}}{V_{DC}}$ = it is found as 434,78 / 220 = 1, 989 A

If the formula (18) is used to find out $E_{induced}$[6];

$$E_{induced} = \frac{P_{out}}{I} = \frac{400}{1{,}989} = 201{,}1\ V$$

$$V_{DC} = I.R_{rail} + E_{induced}$$

$220 = 1{,}989.R_{rail} + 201{,}1$ ise; $R_{rail} = 9{,}50\ \Omega$

4.2.4 Linear Motor Sizing

As stated in the main design objectives, the force required to raise an object 3m up to a mass of 3000N and as mentioned at the beginning, since dimensions of the elevator gain importance as it is desired to work in a narrow area such as stairs, a tubular shaped linear motor shall be designed. Figure 4.5 in the tube-shaped linear motor with straight linear motor, power differences are specified, compared to a straight linear motor.

Parameter	Flat motor	Tubular motor
Maximum force F_{max}, N	221	305
Minimum force F_{min}, N	146	198
Average force F_{av}, N	180	244
Force ripple coefficient k_r	0.42	0.44
Maximum detent (cogging) force F_{cmax}, N	20	45
Armature current I_a, A	8	8

Figure 4.5 Comparison of flat and tubular shaped linear motors with the same current input [6].

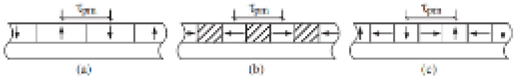


Figure 4.6 In linear motor magnet (a) radial, (b) axial, (c) Halbach knee [7]

In this linear motor design, axial type magnet placement has been chosen. If Halbach type magnet placement is made as shown in Figure 4.6, the desired force will not be obtained. According to evaluation, the lower and upper surfaces in Halbach, two different magnetic fields are occurred. In this case, tubular linear motor design with Hallbach arrays will cause vibration of operation, as well as additional guidance will be required for vibration. The Axial and Halbach strings in Figure 4.7 have been compared for this design.

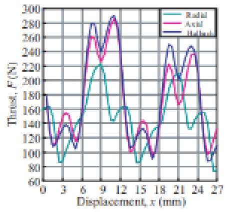


Figure 4.7 Force change according to linear motor magnet string [8].

In the calculation phase, the need for maximum force occurs when the lift is on the upward slope. The force (F_{x2}) becomes the maximum force, in other words F_{max}.

F_{max}= 3053,97 N ≈ 3100 N

Other assumptions related to motor design;

J_a = 10 A / mm^2 (Nominal Armature Current Density)

d_w= 2 mm (Copper Wire Diameter)

τ = 50 mm (Pole Range)

Total mechanical energy must be equal to the total energy stored by the natural magnets.

For the desired thrust force, there must be at least 7 natural magnets (PM, natural magnet) and 3 segments (armatures).

For selection of natural magnets, as can be seen in Figure 3.8, NdFeB was chosen which could be used for more force in the same current range.

Parameter	Quantity	NdFeB	SmCo
B_r	[T]	1.25	1.01
H_c	[kA/m]	950	724
μ_r	–	1.048	1.11
T_c	[°C]	300	850
Working temperature	[°C]	80	300
$(BH)_{max}$	[kJ/m³]	310	203
Temperature coefficient for B_r	[%/°C]	−0.11	−0.04
Temperature coefficient for H_c	[%/°C]	−0.5	−0.27

Figure 4.8 Mechanical properties of natural magnet [6].

In addition to Figure 3.8;
w : Energy Density of Magnets = 400 kJ/ m^2 (for NdFeB)
Electromagnetic force, τ energy required in the polar range;
$W = F.\tau = 3100.0{,}05 = 155$ J (20)
VTo find the energy density;
$V = \frac{W}{w} = \frac{155}{400.000} = 3{,}875\,x10^{-4}m^3 =$
$3{,}875\,x10^5 mm^3$(21)
To find the energy density per each magnet (total calculation done with 7 magnets) [6];
$V_m = \frac{V}{7} = \frac{3{,}875\,x10^5}{7} = 55.357{,}142\ mm^3$ (22)
The polar range is selected as τ = 50mm and Since the ferromagnetic ring (ring) with magnet is thought to be of equal width, [6];
$2.h_m = w_p = \frac{\tau}{2} = \frac{50}{2} = 25$ mm
The inner radius of the magnets should be as small as possible [6];
$r_i = 4$m,
Fortheouterradiusofmagnet (23);
$r_o = \sqrt{\frac{V_m}{\pi.2.h_m} + r_i^2}$ (23)
$r_o = 27$ mm ;
$w_t$armaturearmthickness can be selected as half of magnet thicknesses.
$w_t = \frac{w_p}{2} = 12{,}5$ mm (24)

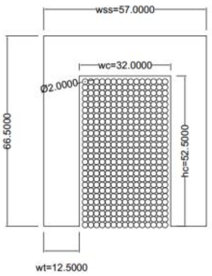


Figure 4.9 Dimensions of armature.

To find natural magnet force[6];
$F_m = 2.h_m.H_c = 0{,}025.950.000 = 23.750$N
(25)

Current calculation; $I_{amax} = J_a.\pi.\frac{d_w^2}{4} = 31{,}4$ A
(26)
To determine the number of copper wire windings, [6];
$N = \frac{F_m/2}{I_{amax}} = \frac{23.750}{31{,}4.2} = 378$ (27)
w_c: 30 mm;
$N = \frac{w_c.h_c}{d_w^{\ 2}}$ ise; $h_c \approx 50$mm
$\frac{w_c}{d_w} = \frac{30}{2} = 15$ the number of horizontal winding.
(28)
When divided by the total number of turns;
N / 15 = the number of horizontal winding = 378/15 = 25.2 ≈ 26
Total number of turns in the new case;
N = 15.26 = 390.
h_c; if it is required to calculate again,
$$h_c = 26\,xd_w + 0{,}5 = 52{,}5\ mm$$
w_s:armature width;
If $2.h_m \le w_s \le \tau - w_t$; (29)
w_s= 32 mm has been selected with arithmetic mean
Since $w_{ss} = w_s + 2.w_t$,w_{ss}= 57mm.
If $n_{ph} = 3$ andw_{ss} = 57mm since the distance between the armaturesand natural magnets;
$d_s = \frac{\tau}{n_{ph}} - w_{ss} + \tau = 9{,}67$mm (30)
If the tubular type linear motor is drawn according to the above measurements;

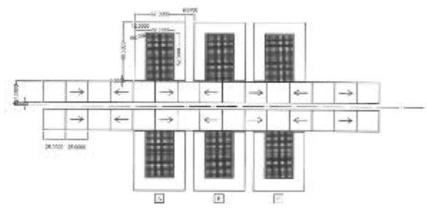


Figure 4.10 Drawing of tubular shaped LM, according to the required force.

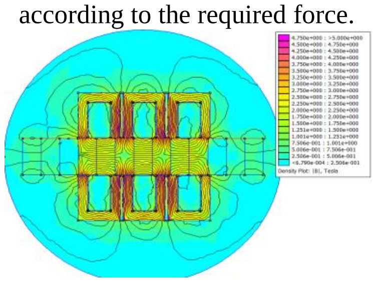


Figure 4.11EMA analysis with FE method with FEMM.

As shown in Figure 3.11, magnetic field analysis was performed using the FEMM (Finite Element Method Magnetics) program. As can be seen from the figure, the magnetic field is concentrated in the middle armature.

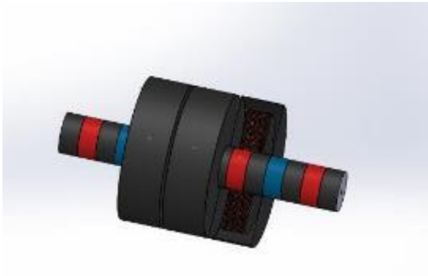


Figure 4.12 According to the above measurements, drawing of Tubular Shaped LM with SW.

In order to ensure that the design of the completed tubular linear motor magnet meets the design objectives, as shown in Figure 4.13, the comparison of the Halbach arrays and the axial magnet arrays was done using the FEMM program.

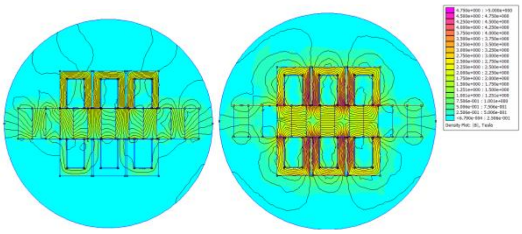


Figure 4.13 Comparison of Halbach (left) array and axial (right) magnet arrays according to EMA.

According to this comparison, axial magnets arrays has been reached proposed force value.

4.3 Platform Type Disabled Lift Design

In order to be able to carry wheelchairs, platform type disabled stairlift is chosen to use in this design.

Therefore, measures of the platform have to match with the dimensions of a standard wheelchair. According to TS 9111: 2011, the dimensions of the platform should be at least 0,75m x 1,20 m [9]. So, the platform dimensions are chosen as 0,80m x 1,30m.

Another important factor of the design is the working direction of the linear motor. According to our selection, since the tubular type linear motor will be used and such a tubular shaped linear motor cannot work on a curve, it should be worked on a straight line. Therefore, the angle of the stairway and the angle of the LM running line should be different from each other.

Due to the good guide of lift and safety objective, three different rails will be used in the design. One of these rails will be mounted to the floor, the other two on the wall. The rails to be mounted on the wall shall be in c profile form. The rail to be mounted on the base shall be in the form of the u profile.

C profiles shall be parallel to each other and parallel to the linear motor operation line.

U profile to be mounted on the floor will follow the base form, that is, on the stair slope.

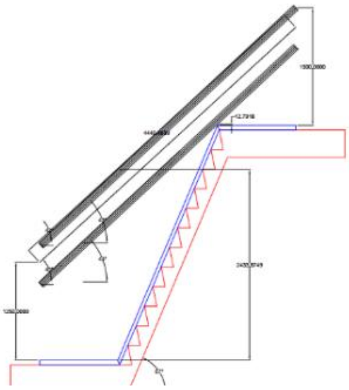


Figure 4.14 Linear motor running rails.

One of the assumptions I made at the beginning of the thesis before the design of the linear motor stairway dimensions and slope. According to this acceptance, the stairway will reach 3000mm at a total of 15 steps and at an angle of 67^o.

Although the lifting platform is designed from 5mm galvanized sheet, the support profiles should be welded and mounted at the bottom of the sheet in order toeliminatenot to bend or not to work on a load of 150 kg.

Lifting platform and 3 railsshould haveconnectedeach other and shouldbeworkedas a whole. So, there should be another rail system to connect each one together on the carrier profiles, which the platform is mounted on. Although, in the existing designs only 2 rails have been, 4 rails should be used in this design. The main reason for this is that the angle of the linear motor and the stair angle are different.

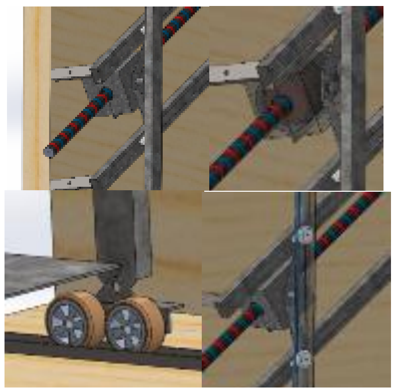


Figure 4.15 SW drawing showing the compatibility of the four rails with each other.

In order to carry out double wheel system is designedfor base rail. For these wheels, forces occur in different directions. This design allows the load to move up or down, it is aimed that the ladder and linear motor pair consisting of different angles are compatible.

Although this design increases the friction force, the carrier vertical prevents the profile from escaping from not running.

V. CONCLUSION

Although linear motors are not widely used until late history, they have been started to be used in almost every sector today. Due to the lack of high precision, no gear, belt, pulley to transform or transmit movement and its suitability to the mass production conditions and its use is increasing day by day.

Design of stair lift driven by linear motor was made and the dimensions of the linear motor are determined according to the design objectives at the beginning of the design. It is observed that these assumptions directly affect the design of the dimensions and since the dimensions of the LM are very important in our system which will work in a narrow space such as stairs, the desired power from the engine should be optimum.

It has been observed that there is a direct proportional bond between the desired force and the outer radius of the magnet. As the desired force increases, the linear motor dimensions also increase proportionally. When the desired force decreases, not only the outer radius of the magnet but also the number of coil windings of the linear motor bobbin and the diameter of the armature will also decrease. In this case, the thickness or forms of the rails, which are used for transport and guiding, will also be reduced.

According to the Halbach system, more power can be obtained in flat linear motors, but axial magnet system is recommended for use in tubular linear motors. In this thesis, comparative FE analysis with FEMM program supports this result.

In this thesis, the issues that I think as disadvantage are as follows: the magnets being open and at an accessible height. So much so that, this may affect the operation of the engine due to the contamination of the magnets as well as causing the deterioration of the devices that may be affected by the magnetic field such as the mobile phone. Due to this reason, for the linear motors that work very closely with people such as stairlifts, magnetic field isolate, protector is required for magnets and motor.

Tubular linear motor use is increasing the magnetic field for the motor but did not create a situation where it did not fit dimensionally. In a narrow area, without further usage of mechanical equipment to transfer the movement, such as the belt, pulley, etc.the guiding and movement can be ensured without the efficiency being reduced.

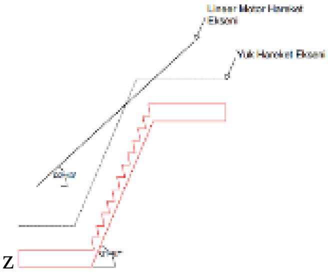


Figure 5.1 Difference in motion axis.

In spite of the disadvantage of not working on curve, it has been proved that the linear motor can be used theoretically in stairlifts, which will work on a curve. As a result, as shown in Figure 5.2, the stair and LM have different in terms of climbing angles, that are LM' s working lineis 67^o, it was observed that the angle of the stair working line was 43 ^{o}; the thesis goal has been reached. Theoretically, it is proved that linear motor can be used in the stairlift.

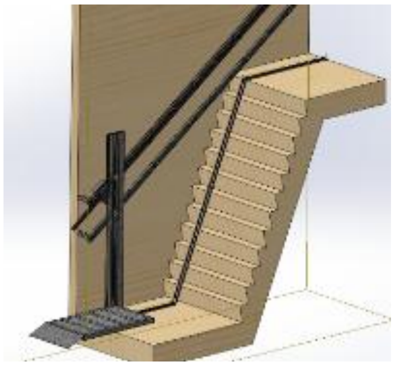


Figure 5.2 SW drawing, showing the installation picture in general lines.

Conflict of Interest
No conflict of interestwasdeclaredbytheauthors.

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