Development of Versatile Home Fitness Equipment

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Abstract. Fitness is one of the necessities of our life. Fitness tells about our health and gives us a good appearance. Fitness doesn't depend on age, the people who don't have time to visit the fitness center do other things to maintain their fitness either by diet or cardio exercise though it keeps them maintain their weight. It doesn't develop the muscles and doesn't give a muscular appearance. For obtaining a muscular appearance people must either go to the gym or want to set up a home gym, setting up a home gym costs a lot and occupies more space. The developed product mostly focuses on home gym setup at low cost and less space. The proposed work is on the design and analysis of multifunctional fitness equipment. The product consists of Dumbbell with free weights, a Centre rod, a bend Bar, a weight hanger, and locking pins. By assembling the Dumbbell with a Centre rod, it can be used as a Barbell rod, by assembling the Dumbbell with a bent rod it can be used as an EZ bar, Dumbbell without free weights and with a weight hanger can be used as a forearm roller and Dumbbell can be also used as Abs roller. So, with a single product with a different combination, the developed product can use 5 different types of equipment. Static structural analysis is also done for the product to ensure its safety.

Keywords: Dumbbell r; Barbell; Ez bar; Forearm roller; Abs roller; Free weights

1 Introduction

Fitness is based on Cardio, Muscle strengthening, and Flexibility [1]. The developed equipment is based on muscle strengthening equipment (i.e., weight equipment). The weight equipment is classified into two types Free weight equipment and Machine weight equipment. On the muscle strengthening side, the versatile home fitness equipment comes under the Free weight equipment. Though there are a lot of inventions on the side of fitness equipment the invention is on the home fitness equipment, uses a quick-lock mechanism and fixed weights [2], which questions the safety of the product and doesn't come in the compact size since they use fixed weights. The equipment uses free weights. There are no fixed weights in dumbbells. The weights are added to the dumbbell rod. The pins are used to lock the weights.

1.1. Need for fitness

In the current lifestyle fitness is the of our basic needs. The US Department of Health and Human Services says that an adult should spare 2 hours 30 minutes a week for fitness [3]. It also recommends including muscle-strengthening workouts at least twice a week. Fitness

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plays a major role in health. Being fit prevents many diseases and keeps the body and mind to stay active [7].

1.2. Types of free weight equipment

Some of the types of free weight equipment are classified below

- Barbell Rod [16]
- EZ Bar [17]
- Dumbbell
- Wrist roller
- Kettlebell weight

1.3. Muscle Groups

The human body's major muscle groups are classified in the following. These groups are activated in the muscle strengthening workouts [4]

- Chest
- Lat
- Shoulders
- Leg
- Arms

These all-major muscle groups are developed by working out with developed versatile fitness equipment. Adding to this abdominal is also an important muscle in fitness.

1.4. Need for Versatile home fitness equipment

As fitness is very important in life but many people don't find time for visiting the fitness center for muscle strengthening. Muscle strengthening is one of the important ways of grooming ourselves. This muscle strengthening is obtained only by weightlifting workouts. For weightlifting workouts, there are two options: working out in the fitness center or creating a home gym and working out. In the current scenario, people don't have to time spare in the fitness center.

Home gym setup has its drawback with the existing equipment

- Lack of Space [10]
- High cost

These are two main drawbacks faced by the people with the current equipment.

The proposed product solves the two problems. Since it is multifunctional fitness equipment. It is the combination of many types of equipment. It occupies the minimum amount of space in a compact size since the combination of the material cost of each piece of equipment gets reduced therefore the cost of the product is also low.

From the developed equipment, many numbers of workouts can be achieved. So, it gives options to the user with many numbers of workouts and keeps the user entertained with different types of workouts as they can do in the fitness center

2 Design and Analysis of the Product

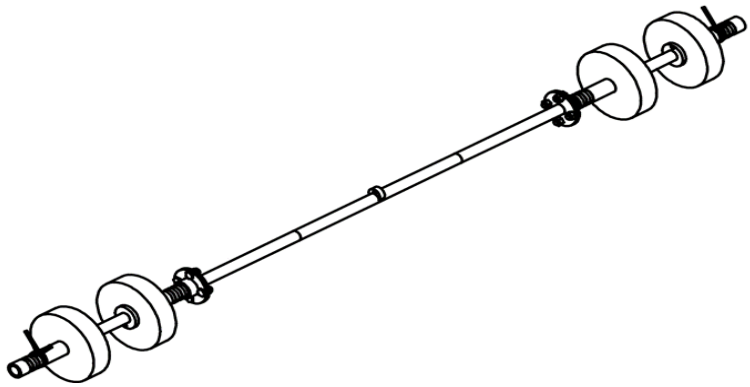

Fig.1 (a) Barbell rod

Fig 1 (a) is the design of the Barbell rod. The design consists of a center rod, and 2 dumbbell rods with free weights, and the weights are locked using the pins. The inner diameter of the pin increased while compressing the sides of the pin and after inserting it into the dumbbell rod if the pressure applied on the pin is released. The pin gets caught in the rod. The grooving is done in the rod so that when the pin gets to lock in the grooved area it provides an extra grip and doesn't allow the weights to slide down. The dumbbell and center rod are connected by the threads. Fig 1 (b) is the isometric view of the EZ bar. Similar to the barbell rod this design also consists of 2 dumbbell rods with free weights and the weights are locked using the pins. This EZ bar consists of a Bend rod instead of a center

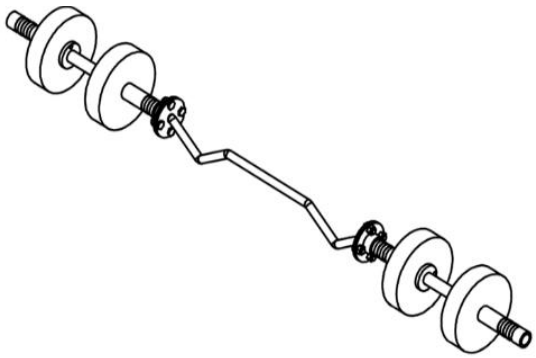

Fig 1(b) Ez bar

Fig 1 (c) is the image of the Forearm roller proposed. The equipment consists of dumbbell rod ropes and a weight hanger. In the dumbbell rod, there is a hole in the side through which the rope is connected and the weight holder is hanged to the rope, and weights are added to the

weight hanger. This type of combination is used to forearm workouts. Fig 1 (d) is the design of the Abs roller. Since this equipment is a combination of 5 five components of equipment the design is made in such a way that different combinations of the components in the equipment, can achieve different types of equipment.

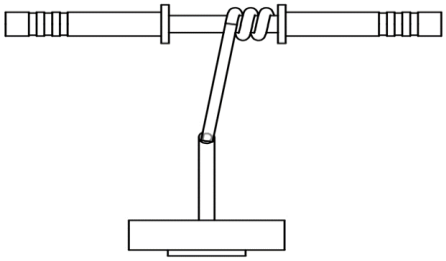

Fig 1(c) Forearm roller

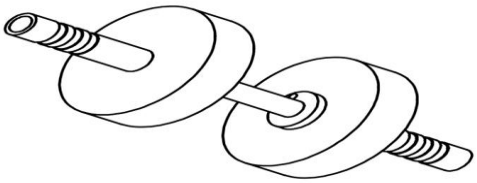

Fig 1(d) Abdominal roller

Fig 1 (c) is the image of the Forearm roller proposed. The equipment consists of dumbbell rod ropes and a weight hanger. In the dumbbell rod, there is a hole in the side through which the rope is connected and the weight holder is hanged to the rope, and weights are added to the weight hanger. This type of combination is used to forearm workouts. Fig 1 (d) is the design of the Abs roller. Since this equipment is a combination of 5 five components of equipment the design is made in such a way that different combinations of the components in the equipment, can achieve different types of equipment.

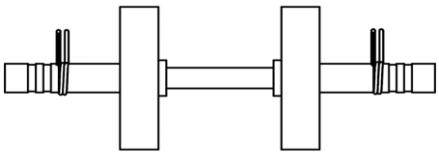

Fig. 1(e) Dumbbell rod

Fig 1 (e) is the design of the dumbbell rod which is similar to the Abs except the two pins are used to lock the weights since the dumbbell is used for different workouts so the locking of

weights plays a major role in dumbbell. Whereas Abs roller is used only for the floor workouts where the weights act as the wheel for the motion so the weights are not locked.

2.1 Name of the components

The following table shows the name of the component and the number of components required for the equipment. Since the equipment that is obtained above is a combination of the equipment. The rod placed in the center of fig 1 (a) is known as the center rod which is an important component for barbell rod assembly. The curl rod in fig 1 (b) is the bent rod which is the important component for the Ez bar assembly. The rod which holds the weight in the barbell rod, Ez bar image, and dumbbell image is known as the dumbbell rod. The circular plate placed in the dumbbell rod is the weight. The component which is used to lock the weight in the figures is known as the pins. A Flange type connector used in barbell rods and Ez bar are known as connecting flange it is locked by nut and bolts. The rope and the hanger are used in the forearm rollers.

Table 1 Name of the components and number of components required

Parts	No of components
Center rod	1
Bend rod	1
Dumbbell rod	2
Pin	4
Weight hanger	1
Rope	1
Connecting Flange component	2
Nut and Bolts	8
Free weights	As required

2.2 Standard Dimensions

There are standard dimensions for the fitness equipment based on the standard had designed the equipment. The length of the barbell rod varies from 5ft to 7.2 ft. The product had designed the barbell rod for 6ft. The diameter of the barbell rod varies the diameter of the developed product's barbell rod is 29mm diameter. [9]

2.3 Design Calculation

The calculation is done for the maximum stress acting on the equipment in the barbell the maximum stress is calculated for the barbell because the maximum weight used in workouts is for bench presses, squats, and deadlifts. These three workouts are done in the barbell rod therefore the maximum stress induced is calculated for the barbell rod. the design and material selection are done according to the analysis report.

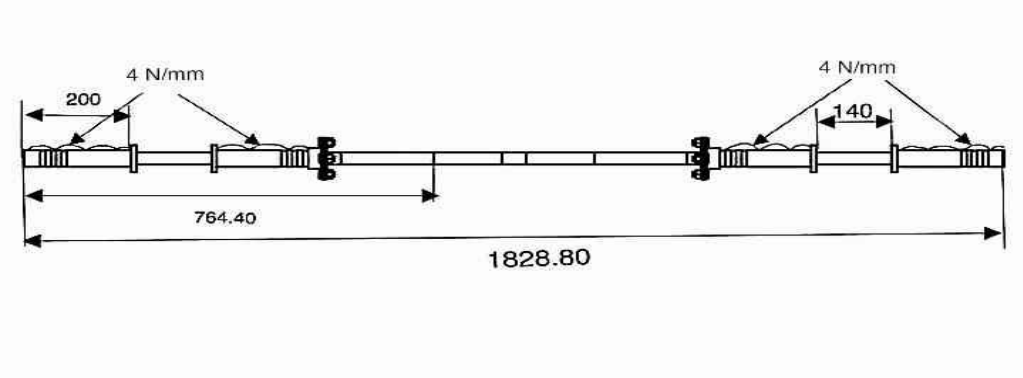

Fig 2(a) Load acting on the barbell rod

The calculation of the maximum stress induced in the component is based on the calculation of total stress induced on the barbell of the heaviest deadlift record [5].

The maximum stress induced in the equipment is calculated by considering the component as an overhanging beam. The fixed point in the barbell is the point where the barbell is holded during a workout. Fig 2(a) shows the load acting on the barbell the load is considered a uniformly distributed load. The load acting is 4 N/mm in four areas and each has a length of 200mm totally of 800 mm. The handle part of the dumbbell length is 140mm. The total load acted on the component is 3200 N. Since this equipment is designed for home gym setup. The maximum load is fixed as 320 Kg.

The barbell rod has different sections to calculate the maximum stress the barbell rod is considered as a 29mm solid shaft and the self-weight of the component is neglected since it is distributed uniformly all over the component.

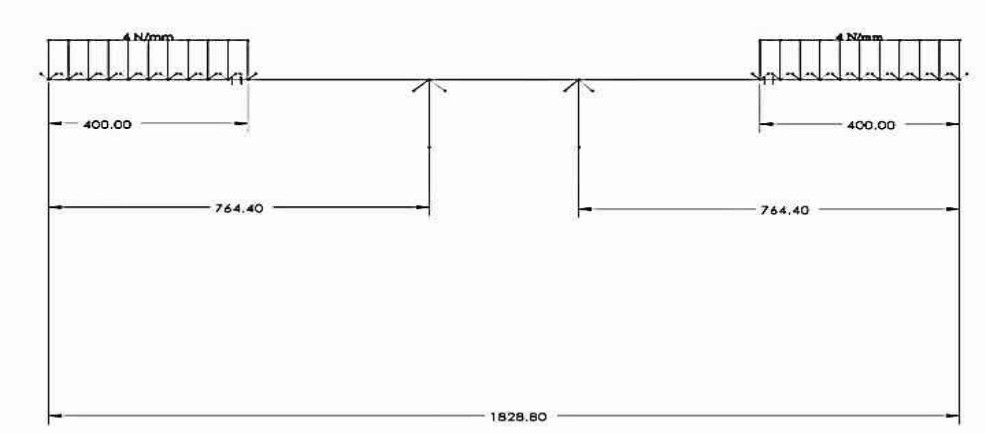

Fig 2(b) Modified diagram of the barbell rod

Fig 2(b) shows a modified diagram of the barbell rod. To reduce the complexity the load acting in the barbell rod on each side is combined and thus forms the uniformly distributed load acting on the component on to edges. The handle distance of 140mm is taken to towards the center, so the loads can move towards the edge of the rod

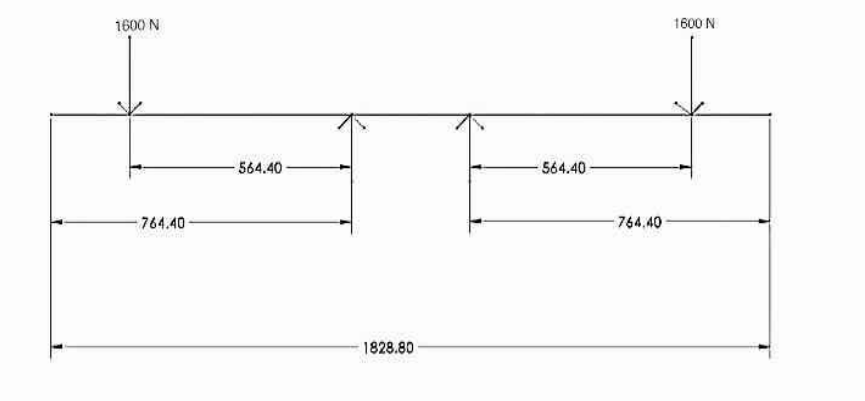

Fig 2(c) Free diagram of the barbell rod and UDL load is converted to Point load

Fig 2(c) shows the free diagram of the barbell rod. The uniformly distributed load is converted in to point load. So, the calculation of maximum stress induced in the rod can be found easily. Since the load acting on each side are equal to each other it is enough to find the maximum stress acting on one side of the beam concerning the fixed support on the side.

I = Moment of Inertia (about bending axis)

$= 0.78r^4$ [5]

$= 0.78(\frac{0.029}{2})^4$

$I = 3.44799 \times 10^{-8}\ m^4$

The moment of inertia about the bending axis is calculated to find the stress i.e., occurred due to the bending of the component.

z = Distance from neutral axis to edge

$= \frac{0.029}{2}$

$= 0.0145$ m

Z = Section modulus of the cross section of the beam

$= \left(\frac{(3.44799\ x\ 10\text{^}-8)}{0.0145}\right)$

$Z = 2.3779 \times 10^{-6}\ m^3$

To find the stress induced in the component moment of inertia, section modulus and the distance from the edge of the neutral axis plays an important role. The stress acting on the component is found by the basic formula of the product of load and distance whole divided by the section modulus.

Stress between the Supports

$\sigma = \left(\frac{Wc}{Z}\right)$

W = Weight = 1600 N

c = Distance between the load and fixed weight

σ = ((Weight x Distance between weight and the fixed point)/ (Section modulus)

$\sigma = \left(\frac{(1600\ x\ 0.5644)}{(2.3779\ x\ 10\text{^}-6)}\right)$

$\sigma = 379.763\ N/mm^2$

From the analytical calculation, the maximum stress induced in the rod is around 380 N/mm^2.The calculation doesn't give the approximate value. Since the cross-section of the rod

throughout the barbell is considered to be the same but in the real case, the cross-section of the barbell rod changes at each place as shown in fig 2(a), and the load acting on the component position is changed for calculation and since it is an assembly there the contacts between components also play a role. The numeric method is used since the analytical method doesn't give value for the barbell cross-section. Before using the numerical method for the calculation. The Design FMEA is done to find the failures and their failure modes in the component.

2.4 Analysis of the component

FMEA is done for the barbell rod as noticed said the maximum load is applied to the Barbell rod [8]. As said in the analytical calculation the maximum load is applied to the barbell rod. Therefore, if failures occurring in the barbell rod are found there is no need to find the FMEA for other combination equipment.

FAILURE MODE AND EFFECTS ANALYSIS

Item: Multifunctional fitness Equipm Responsibility: Gughan Raja E FMEA number: 1
Model: Current Prepared by: Gughan Raja E Page : 1 of 1
Core Team: Gughan Raja E, Ajin M, Abraham JS Jospher FMEA Date (Orig): 20-04-2022 Rev: 1

Product Function	Potential Failure Mode	Potential Effect(s) of Failure	Sev	Class	Potential Cause(s)/ Mechanism(s) of Failure	Occur	Current/Design Process Controls	Detect	RPN	Recommended Action(s)	Responsibility and Target Completion Date	Action Results				
												Actions Taken	Sev	Occ	Det	RPN
Connection Between The center rod and Dumbbell	Thread Failure	The Dumbbell Cannot be locked with the barbell	7		Heavy weights	6	By doing analysis on the product	5	210	Protecting the threads	22-04-2022	Flange type is produced	3	2	1	6
Center rod	Failure of material	Complete failure and poor safety	10		Heavy weights	4	By doing anaalysis of the product	4	160	Select of materials	22-04-2022	Numerical Analysis is done and the material is selcted	10	2	1	20
Flange	Failure of nut and bolts	There no protection for the threads	3		Wear and tear or heavy weights	6	Selection of materials of nut and bolt	5	90	Bolt and nut diameter	22-04-2022	Numerical analysis is done and the material is selcted	3	2	1	6
Pin	Breaking	Can't able lock the weights	2		Rough use	1	Design checking	1	2		22-04-2022		2	1	1	2

Fig 2(d) FMEA of Barbell rod

From the FMEA can able to find the failure of the components in the assembly and their failure modes. The main reason for FMEA since it is the assembly of the components the barbell has many ways of failure, Therefore, by using FMEA the failures based on the Risk Priority Number (RPN) are found. One of the failures is prevented in the design of the equipment itself. Fig 2(d) shows the FMEA of the design. From the figure, As noticed that the connection between the center rod and the Dumbbell got failed due to the thread failure it has the highest RPN. The dumbbell is connected using the thread when a heavy load acted on the equipment. It would cause the thread failure to prevent that a flange type coupling is introduced which protects the thread failure the bolts in the flange coupling protects the threads this failure is prevented in the design itself. Next center rod failure is due to heavyweights. Can be solved by the selection of materials. The flange gets failure due to the nut and bolt shear failure but that failure has RPN below 100 and that failure can also be prevented by a selection of material or size of the bolt. The other failure is not a big issue.

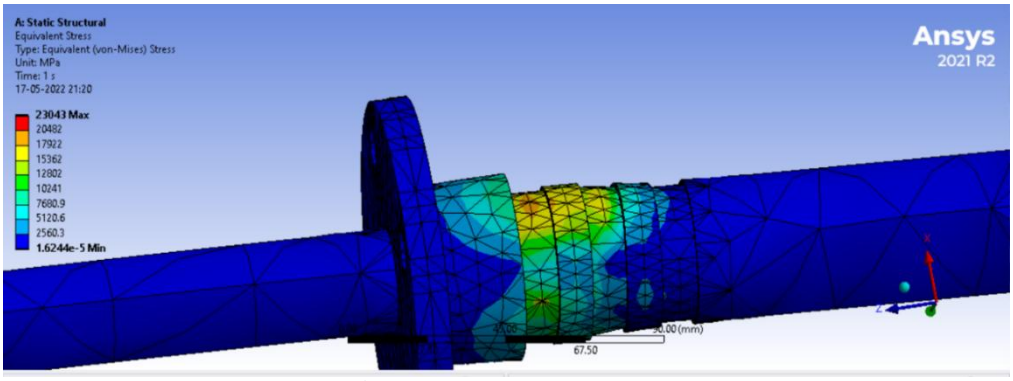

Fig 2(e) Thread failure between the center rod and the dumbbell rod

Fig 2(e) checks whether the thread gets failure when the flange-type coupling nut and bolts are eliminated from the design. The gets broken down at the load 1600N at the single side of the component. Equivalent stress or Von-Mises stress is used to find the maximum stress induced in the component because in the failure theories the equivalent stress value is more accurate compared to the four theories of failure. Thus, the equivalent stress is used to find the maximum stress-induced.

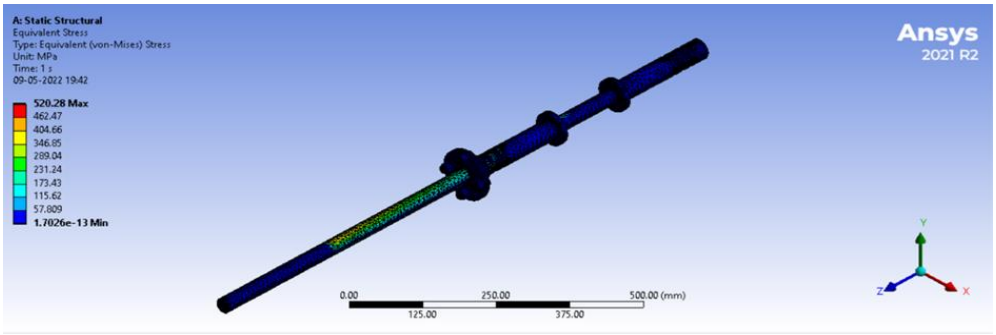

Fig 2(f) Equivalent Stress for Barbell rod

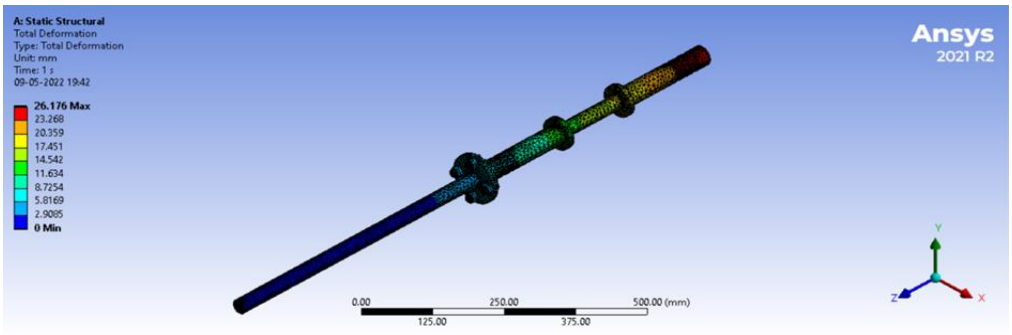

Fig 2(g) Total deformation of barbell rod in mm

Fig 2(f) and 2(g) are the numerical analysis of the component. Fig 2(f) shows the maximum equivalent stress and 2(g) shows the total deformation of the component. The maximum

deformation occurs at around 27mm which is negligible for such heavyweights. Element analysis used is 3D element analysis. The reason for using the 3D analysis is the contact the analytical calculation shows the maximum stress for the single component but here the equipment is the assembly of the components. Therefore, there are frictional contacts between the threaded joints and nuts and bolts, and the other contacts are assumed as frictionless contacts and then analyzed. The tetrahedral meshing is used and made many iterations by controlling the meshing size. In the current figures, the meshing is done in fine size in the critical areas. The hexahedron type meshing is not used since the calculation is tedious. Similar to the analytical calculation the equipment is treated as overhanging beam and to reduce the complexity of the calculation one side of the equipment is taken and calculated. The load is applied on the two faces total load applied is 1600N similar to the analytical calculations. The sliding friction coefficients for the frictional contacts are taken from Mark's standard book of mechanical engineers [6]. The fixed point of the analysis is on the same edge as the analytical component the load and the fixed point are taken from fig 2(a).

The analysis found the maximum stress is induced on the center rod whereas the yield strength of the structural steel is 210 N/mm^2. Therefore, the suitable material for the center rod is low alloy steel 4140, Normalized. In the other areas, the stress is below 200 N/mm^2. Similarly, for Ez bar it is safe to move is low alloy steel 4140, Normalized for the bent rod if it also used for heavyweights but it is designed for home fitness the maximum load used in Ez bar is around 30 kg so it is not necessary to change the material. The barbell used by the professional is made of alloy steel for heavy loads so low alloy steel 4140, Normalized is used for the center rod. The reason for using the low alloy steel 4140, Normalized is its yield strength is 652 N/mm^2.

3 Conclusion

The analysis found the maximum stress induced in the component at the maximum load of 1600 N for the half component the same stress will be acted for the full component with the load of the 3200 N. The reason for designing the equipment for 3200 N for the home fitness equipment is to design the equipment in the fitness center standard. So that the fitness people using this component can increase weights beyond the limitation of the home fitness equipment and this gives them the feel of using the equipment in the standard fitness center. People would always love to use traditional equipment such as a barbell, or dumbbells for workouts. So, the traditional equipment had made some innovations thus it would satisfy the people. The total workouts that can be done using proposed equipment is around 65 workouts [11], [12], [13], [14], [15]. This versatile home fitness equipment is just the first step in innovative fitness. The innovation in traditional equipment attracts the people. It gives them a fulfill and does it also maximize muscle growth.

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