

Developmental Design of an Orthopaedic Recovery System

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Abstract- A developmental design of an orthopaedic recovery system has been conducted. Anthropological data of mass and length distribution of the body segments were used to estimate the components and total length of the main supporting frame and maximum body load that may be accommodated by the system. Vital geometrical, operational load and power parameters were also designed for the required hydraulic subsystems. Results show that the total length of the main supporting frame of the system is 2.237 m and the maximum body load that can be accommodate on the system is 371 kg. The load and power requirements were highest at the hip joint, with the following values: maximum supporting load 2,313.16 N, internal pressure of hydraulic system 379.89 kN/m², buckling load of connecting rod 9252.64 N, critical buckling load of hydraulic system 13370.06 N, required power 86.56 W, expected electrical power input 149.93 W and spring stiffness 6.18 kN/m respectively. When constructed, the developed design is expected to facilitate treatment and recovery of orthopaedic patients. Physiotherapeutic services for body joints related problems would be greatly aided to offer better quality services. Required human involvement and effort on the side of the service providers shall be greatly reduced.

Keywords: Recovery system, anthropological data, operational load, hydraulic system, power

1. Introduction

Patients having neurologic injuries such as stroke, traumatic brain and spinal cord injuries form the largest inpatient populations in a typical comprehensive rehabilitation hospital. These patients typically receive intensive therapeutic care, mostly 2-3 times per week depending on patient recovery progress or other logistics constraints [1]. The effects of musculoskeletal ailment is not central only to the victim, rather, musculoskeletal conditions are a major burden on family members, workplace, health systems, and social care systems [2-3]. Aside from the direct cost associated with the treatment and recuperation of musculoskeletal conditions, the indirect costs are usually predominant. Musculoskeletal disorders, such as low back pain have been found to be a major cause of temporary work disability in many demographics, and consequently contribute to permanent disability pensions [4].

The disciplines primarily concerned with the treatment of muscle-joint-skeleton malfunction and motion impairment are orthopaedics and physiotherapy. Orthopaedics is the diagnosis, care, and treatment of patients with disorders of the bones, joints, muscles, ligaments, tendons, nerves, and skin which make up the musculoskeletal system [5-6]. While physiotherapy has to do with provision of services to individuals and populations to develop, maintain and restore maximum movement and functional ability where movement and function are threatened by ageing, injury, pain, diseases, disorders, conditions or environmental factors [7]. Several factors could be responsible for movement impairment in humans, such as, arthritis, neck pain, rheumatoid arthritis, fractures, low back pain, and osteoarthritis, to mention a few [5-6, 8-10].

Known methods for physiotherapeutic treatment of orthopaedic related problems over the years include: Maitland-the assessment and treatment of the patient's signs and symptoms to develop an effective treatment plan [11]; Cyriax (Orthopedic Medicine)-based on logic and reasoning, that all pain has a source, all treatment must reach the source, and all treatment must benefit the lesion [11-13]; McKenzie-based on "cause and effect", a systematic progression of mechanical forces applied (the cause) utilizes pain response (the effect) to monitor changes in motion, named as the three mechanical syndromes: postural, dysfunction and derangement [14]. Others are acupuncture, muscle energy technique, Mulligan, natural apophyseal glides (NAGS), myofascial therapy, exercise therapy, and massage [15-27]. Tremendous progress has been made on orthopaedic implants for patients



needing surgery or partial replacements of their musculoskeletal system [28-29], and also with orthopaedic rehabilitation devices, actuated with pneumatic muscles to help the recovery of the significant numbers of patients with lower limb bearing joint disabilities [30]. The field of biomechanics applications to human movement is found to be useful for improvement of performance and the reduction or treatment of injury. It is observed that human joints, namely, wrist, elbow, shoulder, ankle, knee, neck and girdle, exhibits motion similar to machine elements, such as, rolling, sliding, combined roll-sliding, spin, compression, and traction respectively [31-34]. Hence, the design and development of a holistic orthopaedic recovery system would be a perfect synergy with the joints in a human body during recovery.

Constant effort is being made in the field of rehabilitation robotics to facilitate the use of robotic devices to assist therapeutic intervention and recovery of patients with movement or posture problems [35-37]. Such devices as robotic machines operate on the principle of electro-mechanics or mechatronics, which combines mechanical, electrical and electronics engineering for electromechanical energy conversion processes [38-39]. Although laudable, robotic machines may require very high skill-set and expertise to operate them, and such level of professionalism may not always be easy to come by especially amongst remotely located health-care facilities or low-income earners.

The motivation for this work is identifying the need to enhance access to physiotherapy and restore movement and musculoskeletal functions, so that patients experiencing orthopaedic related problems can recover effectively. The study focuses on the development of a simple physiotherapeutic mechanical system for orthopaedic patients which can be electrically operated. It involves a design to produce a feasible machine; with a multifaceted system device for enhanced therapeutic applications at different joints in the human body as opposed to a localized application device or system.

2. Preliminary Design Analysis

2.1 Description of the orthopaedic recovery system

For the design under consideration, the orthopaedic recovery system consist of six major supports; namely, head, back, thigh, leg, foot and arm supports. The adjustments of the supports to desired positions shall be based on electromechanical principles, in which the various joints and supports will be controlled automatically when exercising or moving the body joints at a suitable range of movement. An electrical interface is expected to direct and regulate the mechanical system to aid the movement of various components for each intersecting joint member to experience the required range of motion depending on the particular need and rate of recovery of the patient.

2.2 Dimensional considerations for the orthopaedic recovery system

2.2.1 Sectional dimensions

The body dimensions used for design were estimated from the anthropometric, mass distribution and skeletal joint centres data obtained by stereo photographic techniques [40]. The design dimensions as shown in Figure 1 for the five major sections of the orthopaedic recovery system are listed as:

1. Length of head support : $AB = 0.329$ m
2. Length of back support: $BC = 0.587$ m
3. Length of thigh support: $CD = 0.434$ m
4. Length of leg support: $DE = 0.600$ m
5. Length of foot support: 0.287 m
6. Length of arm support (from shoulder to tip of middle finger): 0.841 m (upper arm- 0.352 m, fore arm- 0.288 m, hand length- 0.201 m)

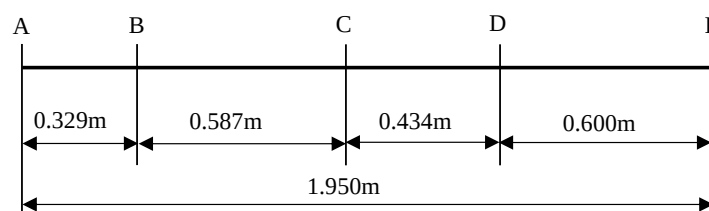


Figure 1: Diagram showing the total length of the system

2.2.2 Mass of body segments

The load that each segment of the system would carry was estimated as the design load. The design load is the upper estimate of forces that a load bearing member is expected to carry [41]. An average adult body mass is range between 63.3-97.7 kg [40, 42]. A design load of 120 kg was used for analysis. Various masses of body segments given in Table 1 were used to estimate mass distribution for each segment of the body by interpolation.

Table 1: Mass distribution of the body segments

Body segment	*Total body mass			Estimated design load	
	Small (63.30 kg)	Medium (85.10 kg)	Large (97.70 kg)	Mass (120.00 kg)	Weight (1,177.20 N)
Head	4.00	4.20	4.40	5.40	52.97
Neck	0.90	1.10	1.20	1.47	14.42
Thorax	18.60	24.90	30.50	37.46	367.48
Abdomen	1.90	2.40	2.90	3.56	34.92
Pelvis	8.60	11.80	14.60	17.93	175.89
Thigh	7.70	9.80	11.80	14.49	142.15
Calf	3.10	3.80	4.50	5.53	54.23
Foot	0.80	1.00	1.10	1.35	13.24
Upper arm	1.50	2.00	2.40	2.95	28.94
Fore arm	1.10	1.40	1.60	1.97	19.33
Hand palm	0.50	0.50	0.60	0.74	7.26

*Source: Anthropology Research Project [40]

3. Detailed Design Analysis of Critical Parts

3.1 Design of the structural frame

3.1.1 Determination of bending moments and shear forces of the frames

In order to conduct the structural and strength analysis of the system so as to obtain the total geometrical cross-sectional area and complete physical dimensions of members of the system, the schematic and free body diagrams of the system was set-up as shown in Figures 2 and 3. The parts numbered (1) to (6) in Figure 2 represent the major body supports of members of the system.

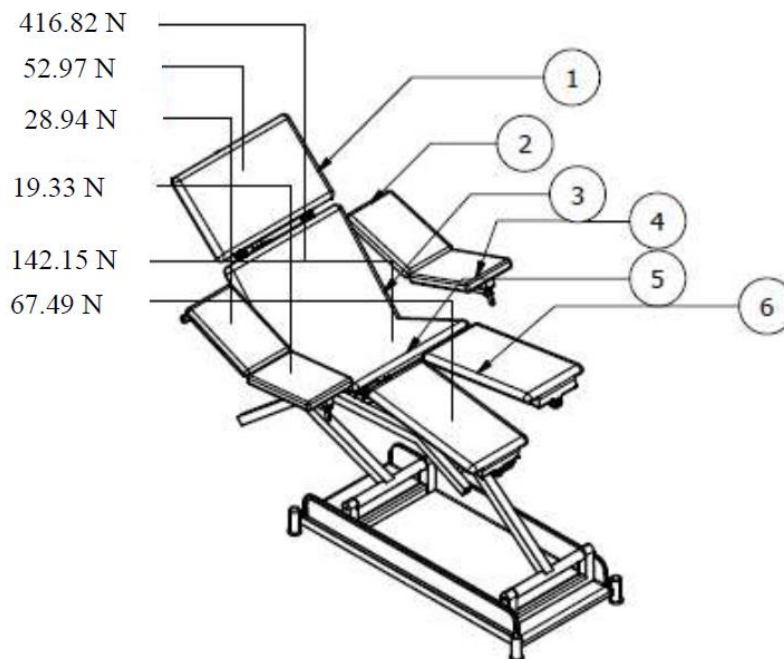


Figure 2: Schematic diagram of major body supports of the system

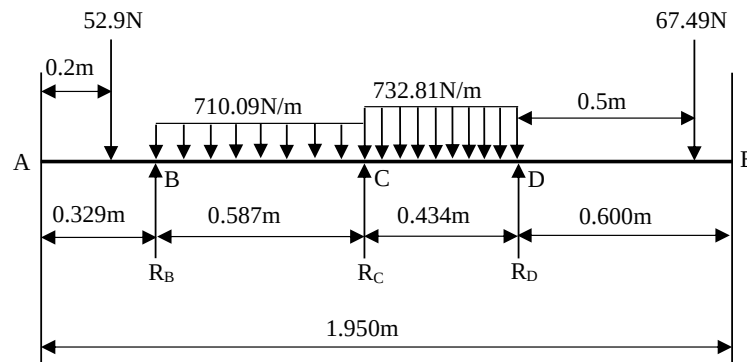


Figure 3: Free body diagram of the system

Applying the equations of static equilibrium and Clapeyron's theorem [41] of three moment equation for a two-span continuous beam of three consecutive supporting points (BCD) to the free body diagram of Figure 3, the bending moment at point C was obtained by equation (1). The method allows the bending moments at B and D to be obtained at first by taking moments about points B and D to obtain $M_A = -M_B$ and $M_E = -M_D$ thereafter the bending moment at point C.

$$M_B BC + 2M_C (BC + CD) + M_D CD = \frac{\omega_{BC} (BC)^3}{4} + \frac{\omega_{CD} (CD)^3}{4} \quad (1)$$

Where,

$$\omega_{BC} = 710.09 \text{ N/m}, \quad \omega_{CD} = 732.81 \text{ N/m}$$

The moments at the supports B, C and D where determined as

$$M_B = 6.833 \text{ Nm}, \quad M_C = 15.783 \text{ Nm}, \quad M_D = 33.745 \text{ Nm}$$

The reactions at the supports B, C and D where determined as

$$R_B = 288.271 \text{ N}, \quad R_C = 376.834 \text{ N}, \quad R_D = 190.145 \text{ N}$$

The values of the bending moment and shear forces determined above were used to obtain the bending moment and shear force diagrams of the orthopaedic recovery system as shown in Figures 4 and 54 respectively. Furthermore, they were also used to estimate the cross-sectional dimensions of members of the system.

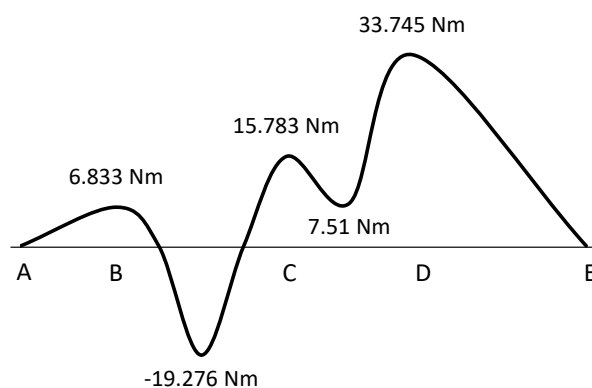


Figure 4: Bending moment diagram of the system

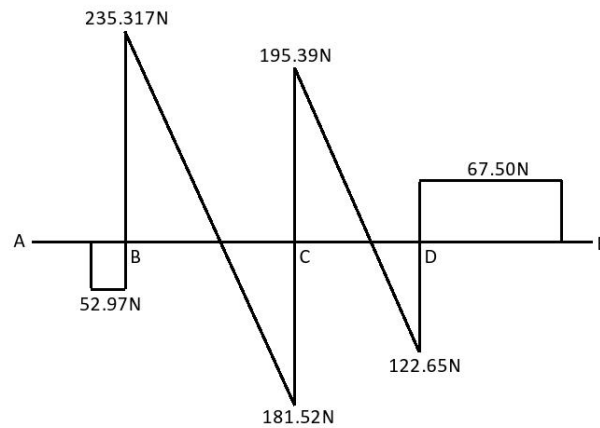


Figure 5: Shear force diagram of the system

3.1.2 Cross-sectional analysis of the frames

If each section of the frame structure is assumed to be a simply supported beam, then the maximum deflection of a section can be expressed as:

$$\delta_{\max} = \frac{5\omega L^4}{384EI} \quad (2)$$

where, $\delta_{\max}$ is the maximum deflection, L is the length of the section considered, E and I are the Young's modulus of elasticity and second moment of area respectively. The allowable deflection of structural members is given by:

$$\delta_{\text{allowable}} = \frac{L}{240} \quad (3)$$

Using a structural steel pipe with the following specification conforming to IS: 4923 – 1997; minimum yield strength, 210 MPa, and minimum ultimate tensile strength (UTS), 330 MPa [43]. And the Young's modulus of elasticity for steel is taken as 200 GPa. Hence, by equating equations (2) and (3), the second moment of area can be expressed as:

$$I = \frac{240}{L} \times \frac{5\omega L^4}{384EI} = \frac{240 \times 5\omega L^3}{384E} \quad (4)$$

Therefore for the specified length CD of 0.434 m, the second moment of area was determined as $I = 9.36 \times 10^{-10} \text{ m}^2$.

For a solid cross-section of uniform dimension, the second moment of area can be expressed as

$$I = \frac{bh^3}{12} = \frac{b^4}{12} \quad (5)$$

where b and h are the width and height of the cross-section respectively. Consequently, the width and height of the cross-section was determined as: $b = h = 0.0103 \text{ m} = 10.3 \text{ mm}$. Hence a minimum solid cross-sectional dimension of $b = h = 15 \text{ mm}$ was selected.

3.2 Design of the hydraulic system

3.2.1 Analysis of sectional maximum operating loads

The orthopaedic recovery system was designed to operate on the principle of hydraulic transmission on the basis of the maximum operating loads. Values of the working loads (F_w) for each hydraulic transmission accessory required for various parts of the system were used together with a factor of safety (n) of 4 to determine the maximum operating loads. The maximum operating loads ($F_{\max}$) for each required hydraulic transmission accessory were obtained as presented in Table 2 by equation (6):

$$F_{\max} = n \times F_w \quad (6)$$

Table 2: Maximum load distribution for hydraulic transmission accessories

Body segment	Estimated working load, F_w (N)	Maximum operating load, $F_{\max}$ (N)
Head	52.97	211.88
Neck	14.42	57.68
Thorax	367.48	1,469.92
Abdomen	34.92	139.68
Pelvis	175.89	703.56
Thigh	142.15	568.60
Calf	54.23	216.92
Foot	13.24	52.96
Upper arm	28.94	115.76
Fore arm	19.33	77.32
Hand palm	7.26	29.04

3.2.2 Design features

The design of the hydraulic system is on the basis of a single acting spring retracting cylinder as exemplified by the cross-sectional representation shown in Figure 6. A single-acting cylinder is pressurized at one end only, with the opposite end vented to the atmosphere through a breather filter or air cylinder or vented to a reservoir (hydraulic cylinder) [44]. The retraction or return stroke of the cylinder is accomplished by an incorporated compression spring, while the ends of the cylinder and piston-rod unit are provided with bearing connections to the main body of the system [44-45]. When the cylinder is pressurized (suction of hydraulic fluid), the hydraulic system experiences an extension due to the displacement of the piston-rod unit from the resting position at one end to the pressurized state at the other end, in which case the free-length of the compression spring is compressed and shortens in length. On reaching the compression limit, the check valve is actuated and opened for the exit of hydraulic fluid and release of pressure. Consequently, the piston-rod unit is then retracted to the rest position due to the extension of the compression spring back to its original length.

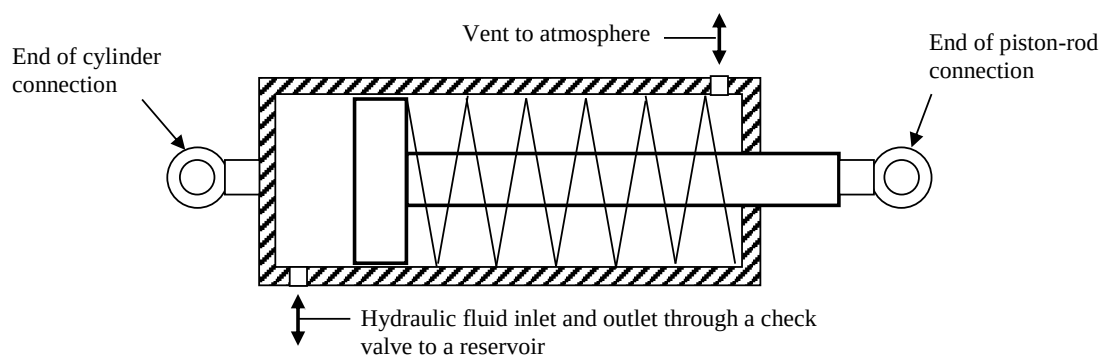


Figure 6: Single acting spring retracting cylinder

3.2.3 Buckling load analysis

The buckling load analysis was conducted in line with Standard for Certification 2.9 [45]. The moments of inertia for the cylinder and the piston-rod can be evaluated as follows:

$$I_C = \frac{\pi(D_o^4 - D_i^4)}{64} \text{ mm}^4 \quad (7)$$

$$I_R = \frac{\pi d^4}{64} \text{ mm}^4 \quad (8)$$

where,

I_C = moment of inertia for the cylinder, mm^4

I_R = moment of inertia for the piston rod, mm^4

D_o = outer diameter of the cylinder, mm

D_i = inner diameter of the cylinder, mm

d = diameter of the piston rod, mm

Since the piston-rod is clamped at one end to the main frame of the system and free to move in the cylinder, therefore the buckling load of the piston-rod can be determined as a clamped-free condition given by [46]:

$$P_B = \frac{\pi^2 EI}{4L^2} = \frac{\pi^2 EI_R}{4L_R^2} \quad (9)$$

where,

E = Young's Modulus of Elasticity = 200 GPa for steel

L_R , length of piston-rod

Assumptions:

1. L , length between mountings in fully extracted position ($L_C + L_{r,v}$) equals 1.5 times of supporting member of the system, L_m :

$$L = L_C + L_{r,v} = 1.5 \times L_m \quad (\text{where, } L_{r,v} = L_C) \quad (10)$$

Hence,

$$L_C = 0.5 \times L = 0.5 \times 1.5 \times L_m = 0.75 \times L_m \quad (11)$$

2. L_S , compressed solid length of retracting spring is 50% of L_C , length of piston-rod or:

$$L_S = 0.5 \times L_C \quad (12)$$

3. D_P , L_P , diameter/thickness of piston is 20% of L_C , length of cylinder or:

$$D_P = L_P = 0.2 \times L_C \quad (13)$$

(internal diameter of cylinder, $D_i = D_P$, tolerance = 1 mm)

4. $L_{S,f}$, free length of spring:

$$L_{S,f} = L_C - L_P \quad (14)$$

5. L_R , length of piston-rod is given as:

$$L_R = 1.5 \times L_C + L_P \quad (15)$$

The acceptable criterion for the buckling load is expressed as [45]:

$$\frac{P_B}{P_a} \geq 4 \quad (16)$$

where,

P_a = actual maximum load = $F_{\max}$ (see Table 2)

P_B = buckling load, N

The diameter of the piston-rod, d was therefore determined from equations (9) and (16), by first stating $P_B = 4 \times P_a$, and consequently determining I_R and d respectively.

The actual maximum load can be expressed in terms of hydraulic system pressure, p and the cross-sectional area of the piston as follows:

$$P_a = \frac{p \times \pi D^2}{4} \quad (17)$$

where, D = diameter of the piston, mm

For control purposes, the Euler breaking or critical load, P_{eu} for a bar with the same dimensions as the piston-rod and with a length corresponding to the fully extracted cylinder is expressed as [45]:

$$P_{eu} = \frac{\pi^2 EI_R}{2 \times L^2} \quad (18)$$

where, $P_{eu} > P_B$

The wall thickness of the cylinder can be determined from the allowable longitudinal stress in the cylinder, σ_a and internal fluid pressure, p as follows [47]:

$$t = \frac{p \times D_i}{4 \times \sigma_a} + 2 \text{ mm} \quad (19)$$

$$\sigma_a = 4 \times p \quad (20)$$

The outer diameter of the cylinder is expressed as:

$$D_o = D_i + 2t \quad (21)$$

3.2.4 Spring stiffness analysis

The analysis of the spring stiffness of the hydraulic systems and consequently spring selection was carried out based on Hook's law, expressed by equation (22):

$$k = \frac{F}{x} \quad (22)$$

where,

k = the spring stiffness

$F = F_{\max}$ = compression load exerted on the springs = the load that must be overcome by the springs during retraction of each component members of the system

x = maximum deflection experienced by the springs during operation

From previous analysis above, the maximum deflection that can be experienced by the springs during operation is 50% of L_R , length of piston-rod:

$$x = 0.5L_R \quad (23)$$

3.2.5 Pumping system analysis

The pumping system is designed on the basis of a volumetric flow rate $V_C / 10 \text{ sec}$. That is, a central pumping system with the aid of checking valves would be incorporated in the recovery system to deliver an internal fluid

pressure sufficient for a positive displacement of any of the piston within 10 seconds of application of pump power. The fluid power P_o can be related to the fluid pressure, p and volumetric flow rate, $\frac{V_C}{10}$ by:

$$P_o = p \times \frac{V_C}{10} \quad (24)$$

Where, the maximum swept volume of each hydraulic cylinder is determined from the inner cross-sectional area of the cylinders and the maximum deflection experienced by the springs during operation. Hence, required power for each of the hydraulic system can be expressed as:

$$P_o = p \times \frac{\pi D_i^2 x}{4 \times 10} = \frac{p \pi D_i^2 x}{40} \quad (25)$$

The expected electrical power input of the pump at a unit power factor of for the hydraulic systems can therefore be determined as:

$$P_{el} = \sqrt{3} \times P_o \quad (26)$$

4. Results and Discussion

4.1 Cross-sectional parameters of the frame

The total length of the orthopaedic recovery system in its completely stretched state was determined from the sectional dimensions shown in Figure 1. Hence, the total length of the system used for the bending moment and shear force analysis was 1.950 m. Furthermore, the total length was also used to estimate the cross-sectional dimension of the frame structure.

The cross-sectional dimensions of the frames could either be circular, square or rectangular, and may be solid or hollow. Considering each section of the frame structure that bears different parts of the body load to comprise of solid square members, and also the most adverse condition of the uniformly distributed load and bending moment exerted on the frame structure with values of $\omega = 732.81 \text{ N/m}$ and $M = 33.745 \text{ Nm}$ respectively; the cross-sectional dimensions of the frame structure were determined.

The minimum cross-sectional area of the frame was obtained as $15 \times 15 \text{ mm}$ (225 mm^2). The solid cross section may however be replaced with a hollow square cross-section to enhance stability during fabrication and for better functional purposes. According to the specification IS: 4923 – 1997 [43], a $32 \times 32 \text{ mm}$ hollow cross-section of 4 mm thickness, and 3.19 kg/m is hereby recommended for the design of the framework of the system. The recommended cross-section results in a cross-sectional area of 240 mm^2 , which is greater than the minimum of 225 mm^2 .

The information on sectional dimensions and mass of body segments earlier determined was used for the analysis of bending moment and shear force analysis of the frames. From Figures 2 and 3, the part AB supports the load of the head, 52.97 N acting at a distance 0.20 m from A; the part BC supports the combined load of the neck, thorax and abdomen (416.82 N) and acts as a uniform distributed load of 710.09 N/m over the span BC; the part CD supports the combined load of the pelvis and thigh (318.04 N) and acts as a uniform distributed load of 732.81 N/m over the span CD; and the part DE supports the combined load of the calf and foot, 67.49 N acting at a distance 0.50 m from D. The above listed spans and loads were used to obtain other geometrical design parameters of the orthopaedic recovery system as presented in Table 3.

4.2 Geometrical parameters of the system

With the aid of equations (7) to (23), the detailed geometrical parameters of the orthopaedic recovery system were determined and presented in Table 3. The length of the supporting frames indicates highest values of 0.600, 0.587 and 0.434 m for the knee, hip and pelvis/thigh joints respectively, while the lowest supporting frames are those of the wrist, ankle and elbow joints with dimensions 0.201, 0.287 and 0.288 m respectively. The lengths of the supporting frames were found to directly correlate with other geometrical parameters of the system. The knee joint resulted in the highest value of length between mountings in fully extracted position (0.90 m), length of cylinder (0.45 m), length of piston-rod (0.765 m), compressed solid length of retracting spring (0.225 m) and free

length of spring (0.36 m). The same goes for other geometrical parameters, such as inner diameter of piston, diameter and thickness of piston (90.00 mm), and outer diameter of piston (101.25 mm). The thickness of cylinder was however the same for the knee and hip joints, while the hip joint resulted in the highest value of minimum diameter of piston-rod with a dimension of 22 mm, followed by the pelvis/thigh and knee joints which both has a value of 13.00 mm. The maximum deflection of spring occurred at the knee and hip joints at 0.38 and 0.37 mm respectively.

4.3 Operational load and power of the system

The operating load and power requirements for the orthopaedic recovery system was conducted using equations (9), (16) to (18), (20), (24) and (25) accordingly as presented in Table 4. The load and power characteristic shows that hip joint possesses the highest values. The maximum supporting load and buckling load of connecting rod were obtained as 2,313.16 and 9252.64 N respectively, while the internal pressure of hydraulic system and expected electrical power input were obtained as 379.89 kN/m² and 149.93 W respectively. The maximum value of spring stiffness for retraction of the hydraulic systems was also at the hip joint with a value of 6.18 kN/m. This was followed by the pelvis/thigh joint, having a value of 2.06 kN/m, while the lowest value of designed spring stiffness occurred at the wrist with a value of 0.23 kN/m accordingly.

These trends were due to high concentration of body load on the supporting frame between the neck and the hip. Consequently, the critical operating load and power requirements for the orthopaedic recovery system are those associated with the hip joint. Table 4 also reveal that values of the critical buckling load were higher than those of the buckling load of the connecting rod of the hydraulic system, hence, validating determined values of the diameter of the connecting rod.

The developmental design conducted in this study affords the option of using a centralised hydraulic pump which is capable of feeding different parts of the recovery system via a distribution network and checking vales as occasion demands. Alternatively, each part can be operated independent of others, since their individual operating parameters have been determined. A decentralised operational system may be preferred when energy is to be conserved. However, a multifaceted network system would be advantageous in instances whereby a particular patient requires physiotherapy at different body joints at the same time.

4.4 Developed orthopaedic recovery system

A 3-D model of the orthopaedic recovery system are presented in Figures 7 and 8, which respectively highlights the partial back/side isometric view, and the partial side/front isometric view of the orthopaedic recovery system. The Figures clearly presents a pictorial representation of the assembled system with required hydraulic systems installed in their respective positions. The Figures also shows installed upholstery material on the system to ensure comfort to users of the system. The maximum body weight the designed system can accommodate should not exceed 371 kg. This maximum value of body weight can be determined from the total sum of the maximum supporting loads of different body parts analysed and used in the design analysis as indicated in Table 4.

Table 3: Geometrical design parameters of the orthopaedic recovery system

Body joints	Length of supporting frame L_m (m)	Length between mountings in fully extracted position L (m)	Length of cylinder L_c (m)	Diameter, thickness of piston D_p, L_p (mm)	Length of piston-rod L_R (m)	Compressed solid length of retracting spring L_s (m)	Free length of spring $L_{s,f}$ (m)	Inner diameter of cylinder, D_i (mm)	Thickness of cylinder t (mm)	Outer diameter of cylinder D_o (mm)	Minimum diameter of piston-rod d (mm)	Maximum deflection of spring x (m)
Neck	0.329	0.494	0.247	49.35	0.419	0.123	0.197	49.35	5	55.52	9	0.21
Hip	0.587	0.881	0.440	88.05	0.748	0.220	0.352	88.05	8	99.06	22	0.37
Pelvis/thigh	0.434	0.651	0.326	65.10	0.553	0.163	0.260	65.10	6	73.24	13	0.28
Knee	0.600	0.900	0.450	90.00	0.765	0.225	0.360	90.00	8	101.25	13	0.38
Ankle	0.287	0.431	0.215	43.05	0.366	0.108	0.172	43.05	5	48.43	6	0.18
Shoulder	0.352	0.528	0.264	52.80	0.449	0.132	0.211	52.80	5	59.40	8	0.22
Elbow	0.288	0.432	0.216	43.20	0.367	0.108	0.173	43.20	5	48.60	6	0.18
Wrist	0.201	0.302	0.151	30.15	0.256	0.075	0.121	30.15	4	33.92	4	0.13

Table 4: Operational design load and power parameters for the orthopaedic recovery system

Body joints	Maximum supporting load $F_{\max}$ (N)	Internal pressure of hydraulic system p (kN/m ²)	Buckling load of connecting rod P_B (N)	Critical buckling load of hydraulic system P_{eu} (N)	Required power P_o (W)	Expected electrical power input P_{el} (W)	Spring stiffness k (kN/m)
Neck	211.80	110.73	847.20	1224.20	4.44	7.69	1.01
Hip	2,313.16	379.89	9252.64	13370.06	86.56	149.93	6.18
Pelvis/thigh	568.60	170.83	2274.40	3286.51	15.73	27.25	2.06
Knee	269.88	42.42	1079.52	1559.91	10.32	17.88	0.71
Ankle	52.96	36.38	211.84	306.11	0.97	1.68	0.29
Shoulder	115.76	52.87	463.04	669.09	2.60	4.50	0.52
Elbow	77.32	52.75	309.28	446.91	1.42	2.46	0.42
Wrist	29.04	40.68	116.16	167.85	0.37	0.64	0.23



Figure 7: Partial back/side isometric view of the orthopaedic recovery system



Figure 8: Partial side/front isometric view of the orthopaedic recovery system

5. Conclusion

A feasible design of an orthopaedic recovery system has been developed in this study. The design of critical parts such as the main frame and hydraulic systems for operating the motion at various joint would facilitate the eventual construction of the system. The total length of the main supporting frame of the system is 2.237 m, while the length of the entire hand supporting frame is 0.841 m. The maximum body load the designed orthopaedic recovery system can accommodate is 371 kg, which far exceed the recommended body size of 97.70 kg for large persons [40]. Results obtained indicate that the hip joint has the highest design specification for load and power requirements. And these were reported in Table 4 as maximum supporting load 2,313.16 N, internal pressure of hydraulic system 379.89 kN/m², buckling load of connecting rod 9252.64 N, critical buckling load of hydraulic system 13370.06 N, required power 86.56 W, expected electrical power input 149.93 W and spring stiffness 6.18 kN/m respectively.

Furthermore, a 3-D representation of the orthopaedic recovery system showing installed upholstery and required hydraulic systems in their respective positions are also included in this study. It is to be noteworthy to mention that the developmental design conducted in this study would go a long way to facilitate treatment and recovery of orthopaedic patients. The system would also aid practitioners in the medical profession in dispensing better quality service at reduced human intervention and labour. Also, the system would contribute immensely to the socioeconomic status of any community and the world at large by ensuring that more and more people are able to become productive once again after experiencing the trauma of musculoskeletal function disorder or body joints related problems.

The study was limited to the design of critical geometric, load and power requirements. Hence, a substantive design of the hydraulic network functionality and detailed electrical application requirements are necessary to enhance the production of the system.

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