SHOULDER PUT INTO EFFECT BY MEANS OF DEVELOPED LOW COST CPM MACHINE

S.S.Metan, Associate Prof., MS(Mechatronics), Pursuing PhD
Dept of Mechanical Engg. Nagesh Karajagi Orchid College of Engineering and Technology Solapur, Maharashtra, India
Dr.G.C.Mohankumar, Prof., PhD
Department of Mechanical Engineering, NITK Surathkal, India
Dr.Prasad Krishna, PhD
Head of Mechanical Engineering Department, NITK Surathkal, India

Abstract

Large number of technological advances that have recently been made in a wide variety of multidisciplinary fields, the boundary between engineering sciences and the relative applications to which they can be applied has become indistinct. Modern devices are being used in advanced mechanical, electrical, and computer systems for various applications, and to assist in research. Medi-mechatronics is the application of the mechatronics in the field of medical science. From the perspective of emerging trend in medical equipment in alteration from hydraulic driven systems to expand equipment functionality, reduce size and weight along with cleaner, safer, and environment friendly electromechanical system is a good choice.

Continuous passive motion (CPM) is a widely used postoperative treatment method that is designed to aid recovery after joint surgery or injury. It can lead to a reduction in both hospital stay and analgesic requirement and accelerates the recovery process. In many physiotherapy centers the use of CPM is limited by the cost of the equipment.

In the present work, design and development of the Low Cost Shoulder CPM Machine is successfully done. The cost of the machine has been reduced by 40% , without compromising the functionality and accuracy of the machine. The machine is tested at one of the renowned Hospitals in Sholapur-India. Thirty patients with shoulder related problems were exercised for different shoulder exercises on CPM machine for two io three weeks. Shoulder joint is observed to be enhanced to normal Range of Motion (ROM) and the patients' pain level has been abridged.

Keywords: CPM, ROM, shoulder, adduction, abduction

Introduction

Mechatronics is a natural stage in the evolutionary process of modern engineering design. The development of the computer, and then the microcomputer, embedded computers, and associated information technologies and software advances, made mechatronics an imperative in the latter part of the twentieth century (C.R.Venkataramana,2003). Standing at the threshold of the twenty-first century, with expected advances in integrated bio-electro-mechanical systems, quantum computers, nano- and pico-systems, and other unforeseen developments, the future of mechatronics is full of potential and bright possibilities. (Robert H Bishop,2006)

Continuous passive motion (CPM) is a postoperative treatment method that is designed to aid recovery after joint surgery. In most patients after extensive joint surgery, attempts at joint motion cause pain and as a result, the patient fails to move the joint. This allows tissue around the joint to become stiff and scar tissue is formed. This results in limited range of motion of the joint and often may take months of physical therapy to recover that motion. Passive range of motion means, the joint is moved without use of the patient's muscles. Due to use of this machine joint receives nutrition, venous flow increases and deterioration of cartilage is being prevented. Also pain is decreased, ROM is maintained. Scientific studies have determined that patients who have troubled achieving the normal range of motion can be benefited by the use of CPM Machine and the recovery is accelerated.

The shoulder complex is the functional unit that results in movement of the arm with respect to the trunk. This unit consists of the clavicle, scapula, and humerus; the articulations linking them; and the muscles that move them. Study of the structures that compose the shoulder unit reveals an elegantly simple system of bones, joints, and muscles that together allow the shoulder an almost infinite number of movements. (Maurel W,1999) The function of shoulder complex is to provide extensive mobility of the arm in space, also to provide stability for elbow and hand skilful or forceful movements. (Lippincott Williams & Wilkins,2009)

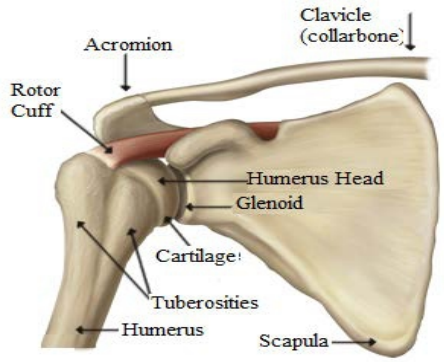


Figure 1. Shoulder joint bones (Courtesy Orthopedic surgery book)

In the present work Low cost CPM machine for shoulder joint has been successfully developed and tested. This will accelerate recovery of the shoulder joint from injuries, operations and other complications. The CPM machine is used for shoulder exercises ranging from abduction, adduction, internal and external rotation, and flexion or elevation. As per the directions from the orthopedic surgeon, the scales of different exercises are set. In the present work some functional modifications with respect to movement; elimination of noise, cost optimization and aesthetic consideration has been implemented successfully.

Literature Review

Shoulder surgery has come a long way in the past fifty years. However, orthopedic surgeons are always looking into ways to improve their results. One persistent problem following joint surgery is stiffness of the joint. In 1926, Von Riemke stated that, after the surgery all the joints should be moved. The movement should be from the first day, should be very slow, as much as possible it should be slow and continuous. Based on a series of experimental investigation, in 1960 Robert Salter, MD, experimented on a rabbit knee joint under continuous compression, and invented the concept of CPM. Salter hypothesized that CPM would accelerate the healing of articular cartilage and particularly structures, such as the joint capsule, ligaments and tendons. (Salter RB. Et al. 1980, 1982, 1984)

Passive motion following injury or surgery has long been the topic of controversy and debate. Early practitioners such as Hugh Owen Thomas vehemently opposed the use of passive motion. However, at the beginning of the 20^{th} century, observations of cardiac surgery wherein the heart muscle heals properly in the presence of constant motion, led the inventor to pursue CPM development till date. Also the short-term efficacy of CPM has been established by numerous clinical studies. When compared with physical therapy alone, the addition of CPM increases active knee flexion in the weeks after arthroplasty. (Chiarello CM, 1997, Harms M, 1991) Prior to the present work, in 2003 Low cost CPM for Ankle joint and in 2009 Low cost CPM for knee joint was successfully developed and tested.

As the shoulder has maximum number of muscles and having maximum degree of freedom, proper care should be given to all the muscles of shoulder, thus it is a critical machine. The machine should work without jerk and it should be very smooth, slow and continuous in operation. The primary aim of the current research is to utilize the shoulder therapy in large number of hospitals in India. The lofty cost of machine is a big concern for its use in the rehabilitation centers in India.(London N J, 1999) By using latest cost effective control method, the labor, the machining, and material cost in India are comparatively low. The cost of the machine has been

reduced by 40% without compromising the functionality and accuracy of the machine. “Low cost Shoulder CPM Machine” is developed and tested successfully on 30 patients in one of the renown Hospital in India.

Design of CPM machine

Orthopedic Requirements:

a. Range of Motion :
   1. Abduction/Adduction : $0\text{-}30\text{-}175^0$
   2. Internal/external rotation : $90\text{-}0\text{-}90^0$
   3. Flexion/elevation : $0\text{-}35\text{-}175^0$

b. Modes of operation : Abduction , adduction,internal or External Rotation, flexion or elevation.

c. Patient size : From 1.4 to 2m.

d. Maximum weight of arm : 5% of Body weight (for 100Kg) 5Kg

e. Pause in movement limit : From 1 second to 30 seconds.

f. Easy to read : HMI display.

g. Revolution of motor : 2 to 5 rpm.

h. Ergonomic consideration : Rest for healthy arm , Fully adjustable chair,less noise and smooth operation.

Kinematic Analysis

In kinematics analysis, a particular mechanism has been investigated based on the geometry of mechanism, input angular velocity, angular acceleration etc. For kinematic analysis of a machine, it may be represented in the skeleton form which is known as mechanism.

Though open and closed kinematic chain exercise are used for the exercise of the human joints. Open kinematic chain can be the best approach for the shoulder joint motions as the movement occuring through a single joint i.e. Gleno-humeral joint. Open kinetic chain exercises are usually performed in a non weight bearing position and allow involved limb to move freely, which is required to perform on the post operative shoulder joint.

Open kinematic chain analysis is used to find out the motor ratings for CPM machine.

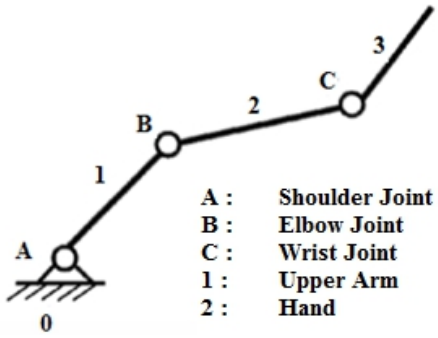


Figure 2. Open Kinetic Chain System.

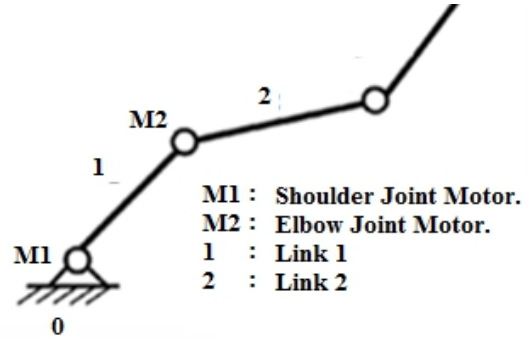


Figure 3. Schematic diagram of Shoulder CPM Machine.

Design Concept

The design concept involves various mechanisms that transfer motion and forces from source to an output. The motion required to be imparted on the shoulder is the circulatory motion which can be easily obtained from the open kinematic chain mechanism. In the open kinematic chain mechanism one of the links is connected to the driving unit such as the motor to have the rotating motion. This constitutes the higher pair with the other links which gives rise to the rotary motion to the other link. One more link which is free, is an adjustable lever type link and gets required circulatory motion due to rotary motion of its preceding link.

Design of Motor-1 (M_1)

M_1 is used for adduction and abduction range of motion. For designing M_1, weights of all the linkages are considered in calculations, i.e.from upper arm to fore arm and dead weight of hand. These weights are uniformly distributed over the upper and forearm assembly.

Vertical Reaction (VA) : $\sum V = 0$

$$V_A = 32.75 \times 0.3 + 18.4 \times 0.16 + 50.026$$

$$V_A = 62.795\ N.$$

$$V_B = 18.4 \times 0.16 + 50.026$$

$$V_B = 52.97\ N.$$

$$V_C = 50.026\ N.$$

Bending Moment is equal and opposite to the torque developed.

Taking Moment about **A**.

$$32.75 \times \frac{0.3^2}{2} + (18.4 \times 0.16) \times \left(0.3 + \frac{0.16}{2}\right) + 50.026 \times 0.46 - M_A = 0$$

M_A = 25.60 Nm.

Therefore $M_A = T = 25.60$ Nm. Torque T = 25.60 Nm.

Taking Moment about **B**.

$$50.026 \times 0.16 + 18.4 \times \frac{0.16^2}{2} - M_B = 0$$

M_B = 8.24 Nm.

Power (P)

The relation between power and torque and is given by

$$P = \frac{2\pi NT}{60}$$ (Josef Edward Shigley, 2003)

Where, N= Rpm (Revolution per minute) of the motor shaft (rpm)

T=Torque required to take the load (Nm)

$$P = \frac{2*\pi*6*25.60}{60}$$

P = 16.09 W.

Considering Factor of Safety (F.S.) as 1.3, P = 21 W (Josef Edward Shigley, 2003)

The standard motor available in the market is of 25 W. (F.S. = 1.55) Power of the motor is 25 W. For this Power the torque will change to **39.788Nm.**

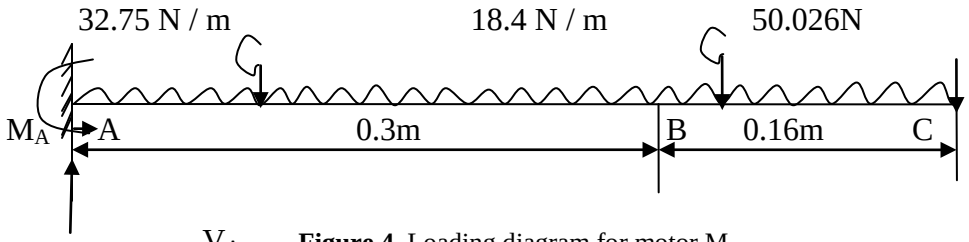


Figure 4. Loading diagram for motor M_1

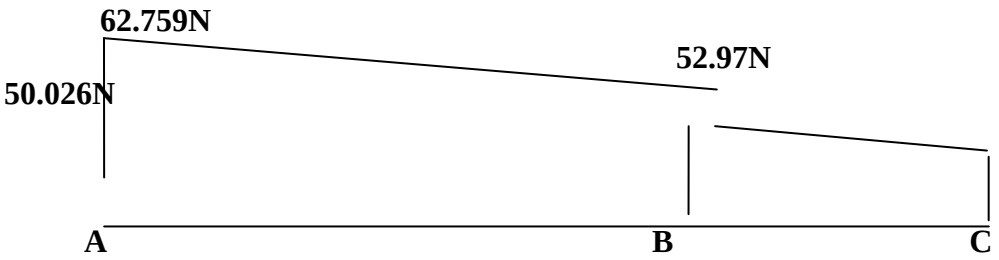


Figure 5. Shear Force Diagram for motor M_1

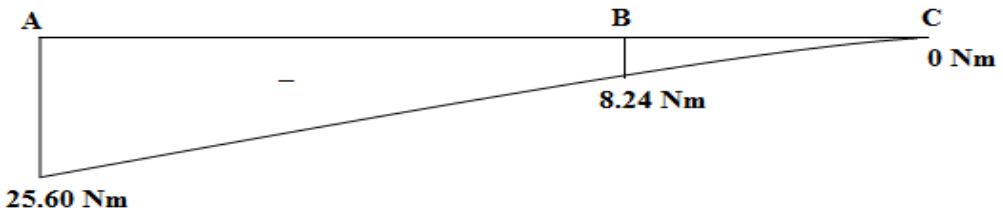


Figure 6. Bending Moment for motor M_1

Diameter (d)

The relation between torque and diameter. Material for the shaft is stainless steel.

$$T = \frac{\pi}{16} * f_s * d^3$$

Where, f_s = Allowable Shear Stress for the stainless steel (N/mm^2) = 520MPa

d =Diameter of Shaft (mm) (Josef Edward Shigley, 2003)

$$39.78 = \frac{\pi}{16} * (520*10^6) * d^3$$

$$d = 7.304*10^{-3}\ m \qquad d = 7.304\ mm$$

The nearest standard shaft diameter available is 8 mm.

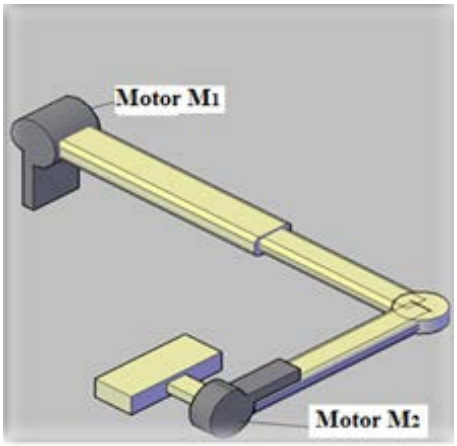


Figure 7. Shoulder arm plot for Motor M_1 and M_2.

Figure 8. Shoulder CPM Chair during Fabrication.

Chair ergonomics considerations

Ergonomics draws on many disciplines in its study of human and their environments, including anthropometry, biomechanics, mechanical engineering, industrial engineering, industrial design, kinesiology, physiology and psychology.

In case of shoulder CPM machine the ergonomics consideration for chair design plays an imperative role, while exercising on CPM machine patient must feel comfortable as he is having injuries and it should be adjustable according to patient requirements.

A shoulder CPM is applied to a joint after trauma or surgery to reduce swelling and scar, the chair is designed based on the size of the person. The locking screw is provides its use for wide range patient size. Different aspects of ergonomics for chair such as seat height, seat width, Lumbar support, Back rest, seat material, arm rest, swivel etc are considered.

Electronics design

The hardware part mainly consists of the PCB, Programmable Logic Control (PLC), Motors and different electronic components used in the circuitry, while the software part consists of the PLC programming.

The hardware which mainly consists of three main circuits:-

1. Power supply circuit. 2. Motor circuit. 3. Control circuit.

Power supply circuit

For PLC application switched mode power supply is used. A switched-mode power supply (SMPS) is an electronic power supply that incorporates a switching regulator to convert electrical power efficiently. SMPS transfers power from a source like the electrical power grid to a load (such as in PLC) while converting voltage and current characteristics.

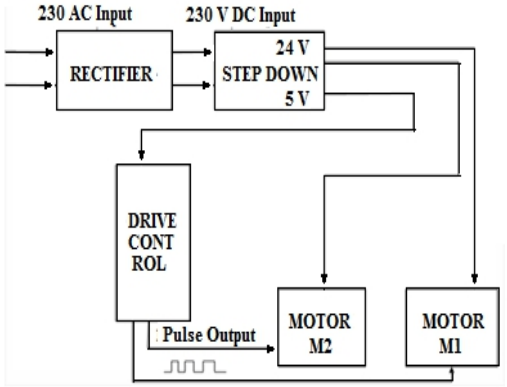


Figure 9. Power Supply Diagram.

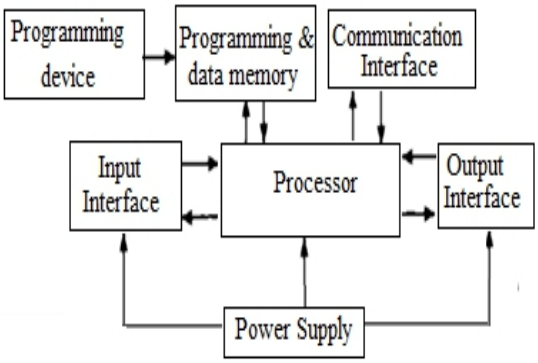


Figure 10. PLC System Block Diagram.

Circuitary for Stepper Motor Control

Stepper motors are easily controlled with PLC; however logic and drive electronics are little bit complex. PLCs have the great advantage that the same basic controller can be used with a wide range of control systems. PLCs are similar to computers but whereas computers are optimized for calculation and display tasks, PLCs are optimized for control tasks and the industrial environment.

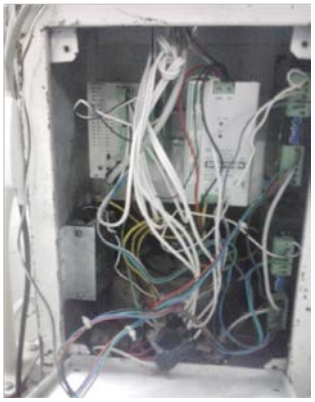


Figure 11. Rear view of stepper motor PLC control unit.

Figure 11. shows rear view PLC system which has the basic functional components of processor unit, memory, power supply unit, input/output interface section, communications interface and the programming device.

Delta PLC DVP 28SV 11T, 28SV PLC is a 28 pointers in column 16 inputs and 12 outputs is used as a control device. This consists with 16K steps program memory that will collect with all Delta series extensions models including digital input/output and all kinds of new high speed extension models.

Fabrication details

3.1 Backrest, armrest: Adjustable backrest in height and angle to a position the patients for comfortable seating is fabricated. It is 18 inches wide so that wide range of patients can be exercised and also it supports the natural curve of the spine. The backrest is made of mild steel and on which cushion is pasted by adhesive and is covered with resin cloth.

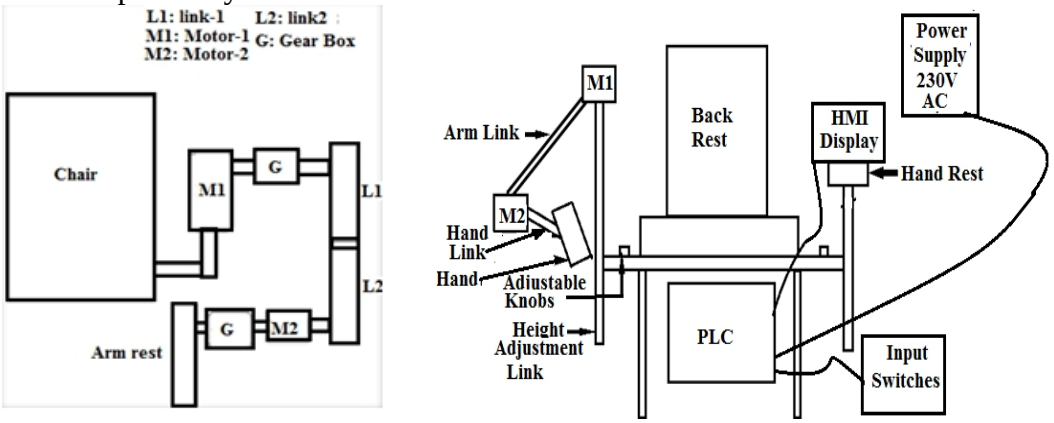


Figure 10. Block Diagram of CPM Machine Assembly.

3.2 Holding tube for length adjustment (upper arm): The vertical upward and downward movement of the holding tube is used to adjust the upper arm length of shoulder joint. The material used for the tube is carbon steel.

3.3 Seat width and depth: The seat has enough width and depth to support any user comfortably. It is 22 inches wide and 4 inch deep. Leather with cushion is used for seat.

3.4 Armrests: It allows the patient to rest the arm comfortably and shoulder in relaxed position. The forearm rests lightly and is sheltered with the cushion.

3.5 Motor (M_1) and (M_2): The motors are used to permit fully isolated movements; the motors can individually be turned on or off. M_1 effects

adduction and abduction. M_2 effects internal and external rotation. Stepper motors are used for the shoulder CPM.

3.6 PLC Controller: Delta PLC DVP 28SV 11T, 28SV PLC is a 28 pointers in column 16 inputs and 12 outputs is used as a control device.
The inputs to PLC are given through Human machine Interface (HMI).

Figure 11. Exercise on Shoulder CPM Machine

Material and method

In present work, 30 asymptomatic subjects were tested on the Shoulder CPM machine in one of the renown Hospital in Sholapur, India. The CPM machine was passed through series of motions for different exercises, such as adduction, abduction, flexion, elevation, internal rotation and external rotation for 2 to 3 weeks.

The CPM machine was conceded throughout a series of motions from 30º to 130º and progressing of 5º increment until a normal range of motion is achieved .(Jesse E Bible et al. 2009) Patient's progress report is generated and one of the sample reports is given below. In the report a gradual increase in ROM is observed on daily bases. From reports one can say that a CPM machine is full proof and is satisfactorily used for different shoulder exercises.

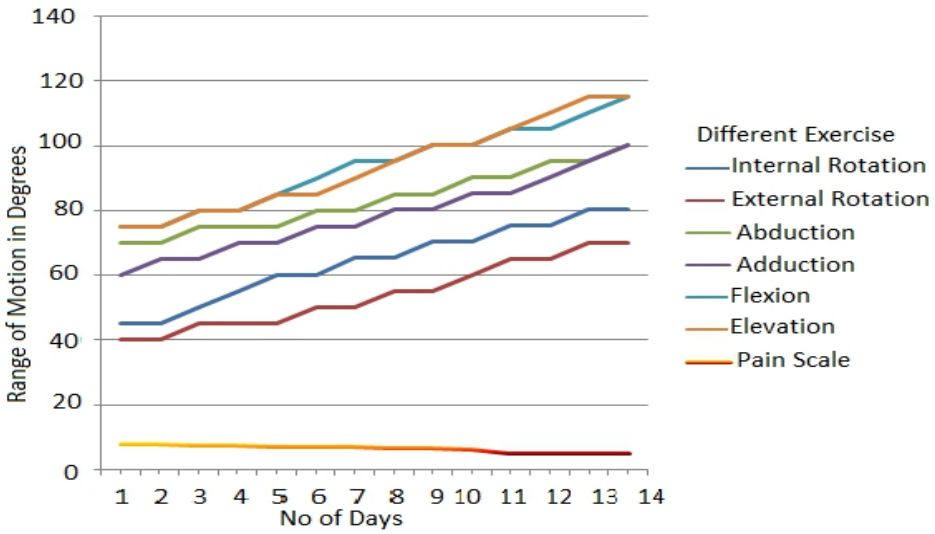
Test report
Date: 3 /12 /13

Name	: Bansode Avinash	Age	: 40
Gender	: Male	Occupation	: Writer
Dominance	: Right hand usable		
Chief Complaints	: Elbow bending, Pain in left shoulder, night cry.		
History	: 4 month old supracondylar fracture of humerus (left), trauma.		

Table: Range of Motion (Shoulder Patient)

Exercise	**Range of Motion in Degrees**														
Day	**01**	**02**	**03**	**04**	**05**	**06**	**07**	**08**	**09**	**10**	**11**	**12**	**13**	**14**	**%R**
Internal Rotation	45	45	50	55	60	60	65	65	70	70	75	75	80	80	88.8
External Rotation	40	40	45	45	45	50	50	55	55	60	65	65	70	70	77.7
Abductio	70	70	75	75	75	80	80	85	85	90	90	95	95	100	57.1
Adductio	60	65	65	70	70	75	75	80	80	85	85	90	95	100	57.1
Flexion	75	75	80	80	85	90	95	95	100	100	105	105	110	115	65.7
Elevation	75	75	80	80	85	85	90	95	100	100	105	110	115	115	65.7
Pain Scale	8	8	7.5	7.5	7	7	7	6.5	6.5	6	5.5	5.5	5	5	50

Figure 12. Exercise on Shoulder CPM Machine.



Doctors Remark: After two weeks of shoulder exercise patients pain and range of motion is improved. As the patient has undergone a surgery 4 months back for supracondylar fracture of humerus, he needs further two to three week shoulder therapy on the CPM machine to get to normal ROM. The progress is satisfactory.

Conclusion

Continuous passive motion started immediately after surgery seems to be an effective method both for allowing complete and quick recovery of the shoulder joint and also , for reducing the risk of early degenerative joint disease. A successful attempt is made in design and development of "Low Cost CPM Machine for Shoulder joint". The machine is tested at one of the renowned Hospitals in Sholapur-India. 30 patients with shoulder related problems were exercised for different shoulder exercises on CPM machine for three weeks. Shoulder joint is observed to be enhanced to normal Range of Motion (ROM) and the patients' pain level has been abridged. In many physiotherapy centers the use of CPM is limited by the cost of the equipment. The manufacturing cost of the machine is reduced by 40% without compromising the functionality and accuracy. Due to the low cost CPM, medium scale hospitals can also afford to use this machine in their physiotherapy center for shoulder rehabilitation.

Acknowledgment

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