BOND GRAPH MODELLING FOR FOREARM OF HUMAN BODY

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Abstract— *Forearm is distal portion between wrist and shoulder in human hand structure. If repeated motion and action is applied to forearm then some pain and fatigue is felt at forearm. Bond graph model of forearm as a dynamic system is constructed using trial version of 20-sim 4.1. 20-sim 4.1 allows only graphical construction of bond graph and simulates this model. Bond graph model of forearm is built using Bowden cable based joint actuation method, Word bond graph object (WBGO) method and hill type muscle and muscle tendon actuation model.*

Keywords *Bond graph, Word bond graph object, Forearm*

I. INTRODUCTION

Forearm is most important portion whenever motion and force transfer occurs between wrist and shoulder. Bond graph modeling is used for graphical representation of dynamic system and predicts behaviour of the dynamic system. Forearm's bones are considered as rigid link and tendons' network considered as string and tube structure in bond graph modeling. Muscle of forearm considered as energy storage elements. Bond graph model of forearm divided in sub model as per bone joints in fingers, wrist and forearm.

II. BOND GRAPH

Bond graph modeling is a very powerful tool to describe dynamic systems as applied to different domains with same nomenclature. Human hands behave like dynamic system when performing daily tasks, so bond graph modeling is a very useful technique for describing behaviour of prosthetics of human hand. The partial impairment means that the hand has lost one or more fingers but retains the ability of its remaining natural fingers. Modern bio-mechanics has developed prosthesis devices which are actuated in a similar fashion like natural fingers.

III. BOND GRAPH MODELING FOR FOREARM MUSCLE RESPONSE

Forearm has very complex structure of muscles, tendons' network and ligaments. It is very difficult to predict forces generated in the forearm muscles. Bond graph gives prediction of behaviour of dynamic system and forearm work like dynamic system when performing daily processes. Hence,

an attempt is made to develop the bond graph model for the forearm muscle.

Bond graph model of forearm is constructed using word bond graph object (WBGO) and Bowden cable based joint actuation method. In WBGO method, each parts of human hand is considered as word bond graph object. For example, tendons' network is considered as transformer and bone joint consider as common flow junction. For preparing the model and approximating the transfer of motion and forces from the hand to the forearm muscles two sets of points are considered on the bone (1) Fixed points are defined on the surface of bones (2) Floating points on tendons which have restricted movement. There are three hook points on the bone. When hand grip force applied, the floating point move with respect to hook point. Due to this movement, problem of soft interference between bones and tendons is eliminated [1].

In Bowden cable based joint actuation method, tendons' networks are consider as string and tube whereas bone joints are consider as pulley and bones are consider as rigid link [1].

For developing the bond graph model, first, the finger joint is approximated by developing sub model. Bond graph sub model for one bone joint of finger of human body is discussed in next section.
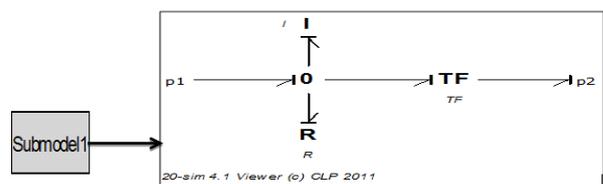

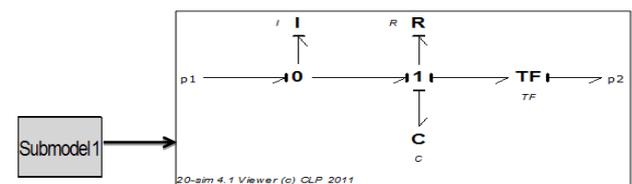Figure 1 Bond graph for one bone joint (Without muscles)

Figure 2 Bond graph for one bone joint (With muscles)

A. Bond graph model for one bone joint without muscle.

The bond graph sub-model for one bone joint of a finger without considering the effect of muscles is shown in Figure 1. The force or effort is applicable to bone joint so that bone joint is considered as 0junction which transmits the force as is to other elements. The power dissipative element R is used to capture the friction and resistance at the bone joint and inertia element I is used to account for the mass inertia applicable at the bone joint. Effort transfers from one bone joint to another bone joint by tendons' network so that tendons' network is consider as transformer element.

B. Bond graph model one bone joint with muscle

Bond graph sub-model for one bone joint of a finger considering the effect of muscles is indicated in Figure 2. The presence of muscle affects the behaviour of the bone joint. The effort is transferred from bone joint to muscles which causes the need to build a1 junction connected also with emerging storage type C element energy storage occurs in muscles when deformed temporarily. Comparing Figure 1 and Figure 3, it is observed that in addition to the added 1 junction and C element, the power dissipating R element is transferred to 1 junction from the 0 junction to capture frictional resistance between bone and muscle joint.

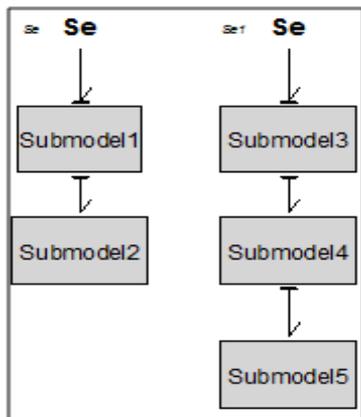*C.* Bond graph for thumb and index finger

Figure 3 Bond graph for thumb and index

As shown in Figure 3, in order to develop models for the fingers and thumb, it can be argued that the thumb has two bone joints and the index finger and other three fingers of a normal human hand have three bone joints so effort transfer from one bone joint to another bone joint by tendons' network. The sub-model discussed for one bone joint with muscle consideration shown in Figure 4.2 is applied to each bone

joint of the thumb and the index finger to develop a sub-model for the thumb and index finger as shown in Figure 3
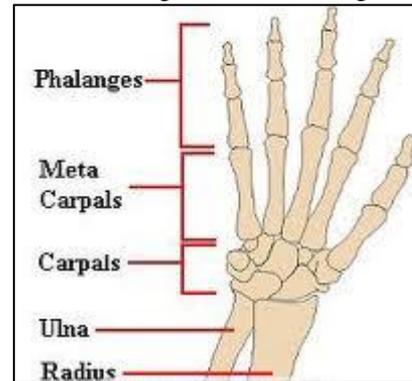

Figure 4 Anatomy of human hand

In Figure 4, anatomy of human hand is shown. Effort applied at fingertip and this effort is transferred from phalanges to metacarpals, metacarpals to carpals and finally transferred into radius and ulna.
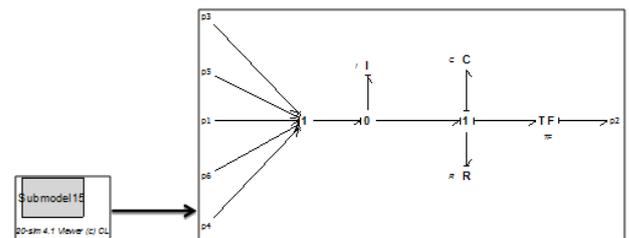
D. Bond graph model for carpals

Figure 5 Bond graph carpal joint

Shown in Figure 5 is the bond graph sub-model for force and motion transfer from Meta carpals to carpals at five points of fingers therefore in bond graph sub-model at the carpal joint, five input ports modeled using effort sources which transfer force to the finger tips are provided. The force and motion induced in the forearm muscles due to the applied efforts are transferred from Meta carpals to carpals and further by tendons' network modeled as transformer. Other than the five input sources of effort from the five fingers, the same considerations are maintained in the bond graph sub-model constructed for the carpal joint as in case of a bone joint in the finger.

E. Equation model:

Equation model is last part of bond graph model of forearm. The equation model describes final response or output of bond

graph model of forearm. In the equation model, power source is considered as the effort p.eat bond graph input port and output signal or response is defined in form of velocity, acceleration and position of muscles of forearm. Velocity signal describes the firing rate of motor unit point during gripping and ungripping by the palm. Velocity signal output is taken in m/sec unit. Position signal indicates change in muscle length during gripping. The variable is plotted against time in conjunction with the applied force p.e on time basis as bond graph response of the forearm muscle. This variable holds the velocity which is the flow variable in this case obtained from the flow p.f corresponding to the bond. Time integral of effort gives the momentum which is the product of mass and velocity. Hence velocity, p.f is obtained by dividing momentum by mass. Displacement in terms of position is the integral of the velocity and acceleration is obtained by dividing force by mass.
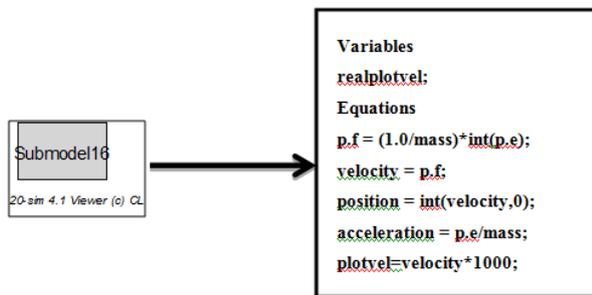

Figure 6 Equation model

IV BOND GRAPH MODEL FOR ENTIRE FOREARM

Bond graph model of forearm constructed using word bond graph object (WBGO) and Bowden cable based joint actuation method. For the preparation of bond graph model for the entire forearm, the considerations can be summarized as:

(1) Tendon's network is considered as simple string and tube modeled using the transformer bond graph element. (2) Bone joint is considered as a junction having existence of frictional resistance, some inertia and transferring force. Appropriate bond graph elements are selected for these phenomena. (3) Bones are considered as rigid links. (4) For preparing the bond graph sub-model for the thumb only two bone joints for phalanges are considered.

The bond graph sub-model of three fingers other than the thumb will be identical to the sub-model for index finger described in Figure 3. Now effort and motion transmit from finger to Meta carpals by tendons' network so that

transformers are employed at last joint of each finger to allow transfer of effort to Meta carpals. The Meta carpals are consider as 1 junction where R element and I element are consider as resistance and mass inertia. Then motion and effort transmit from Meta carpals to carpals which are consider as 0 junction because effort transfer from meta carpal to carpal is the sum of all meta carpals but flow is different. Motion and effort are transferred from carpals to radius and ulna thereafter. Causality analysis of model is automatically performed by software if there is no derivative causality. In this model, since there is not derivative causality, the automatic causality assignment is used.
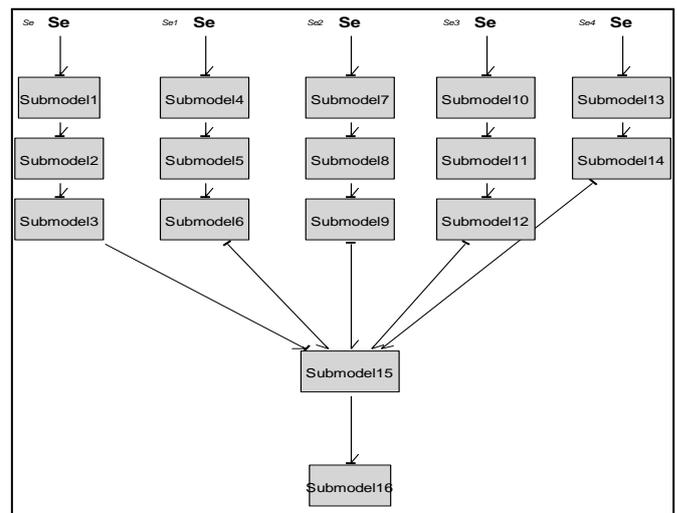

Figure 7 Bond graph model of forearm

Bond graph input parameters values of resistance; capacitance and inertia are set according to Electro myography (EMG) graph. Capacitance values are taken numerically identical for each capacitance in entire bond graph model. Resistance values are set based on lever principal applied to joints in ratio of 1:2for bone joints. Values for inertia properly were set so as to get same peak to peak response age group wise. Values between 10 Kg.m2/radian to 15 Kg.m2/radian are checked and it was found that value of 14.85 Kg.m2/radian for inertia properties gave peak to peak values of response close to EMG data.
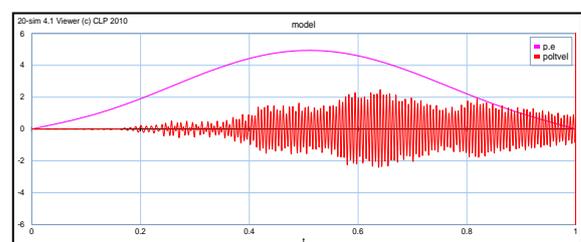

Fig 8: Bond graph response for muscle

V CONCLUSION

After building bond graph model, appropriate values of input variables are decided based on EMG test data and this model is simulated to obtain muscle response during gripping and ungripping action. Input variables of bond graph model were tuned using EMG test responses of muscles. Then these values put in model and response graph of model is plotted. Similarities and differences are found between bond graph output and EMG response measuring peak to peak values in graphs.

REFERENCES

[1]   ]Vaz A and Singh K; "A Bond Graph Model for the Extensor Mechanism of Human Finger"; 14th National Conference on Machines and Mechanisms (NaCoMM09),