CHOICE OF DRIVING SYSTEM (ACTUATOR)

E. Ulén

Summary

When planning an orthotic/prosthetic system, a fundamental difficulty is the choice of the best driving system (motor). The choice is to be made among electric, pneumatic, and hydraulic motors. Different solutions give prostheses and ortheses with different performances, weights, costs, etc. more or less suitable for specific purposes. The supply system will be different for different cases. A very brief discussion on this subject is presented mainly as an introduction to the presentation of the two different development programs that have been performed at the Swedish Institutes for the Handicapped.

Introduction

The performance of a control system is highly dependent on the motor. The performance can be modified by means of feedback (in this case force and velocity feedback are of interest) and/or suitable signal processing. Figure 1 shows a typical general scheme.

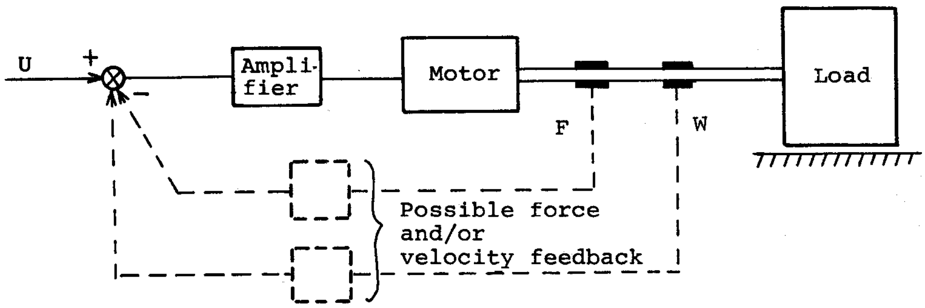

Fig. 1. Typical general scheme for a driving system
U - input signal, F - force as developed,
W - velocity of the motor

The work has been performed at the Research Institute of the Swedish National Defence, coordinated by the Swedish Institute for the Handicapped and sponsored by the Swedish Board for Technical Development.

In the above system it is also assumed that the prosthesis is ridigly attached to a stable support. In some cases, e.g. the elbow case with big torques, the attachment of the prosthesis to the patient may interfere.

The properties of a control system are usually classified as static and dynamic. The properties of the motor are given by the characteristics diagram (force - velocity diagram). Figure 2 shows the general model if true mass load is assumed.

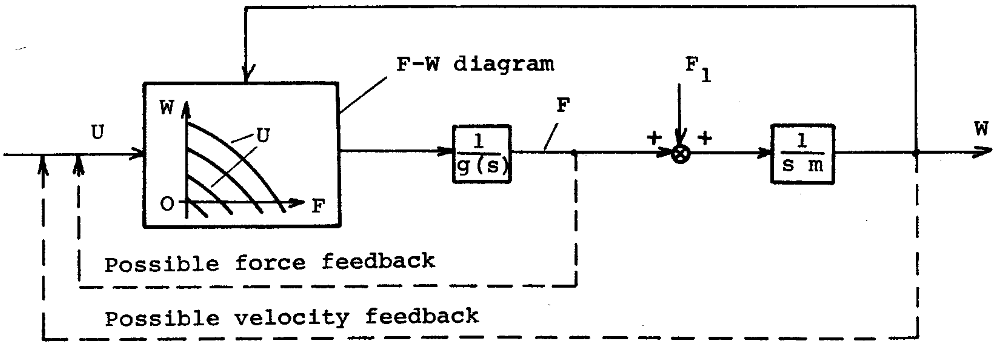

Fig. 2. General model for true mass load
m - mass of load; s - Laplace operator

The F-ω-diagram is valid in the static case, and sometimes, especially with electric motors, can be also approximate in the dynamic situation. In other cases (hydraulic and, above all, pneumatic motors) the force cannot change its value rapidly because of the compressibility of the fluid. In Figure 2 this is expressed by the operator g(s). Important values in the F-ω-diagram are maximum force, maximum velocity and the slope of the curves.

Pneumatic and Hydraulic Systems

General

For the system developed up to now piston or bellow motors have been used. The whole cycle is then incorporated within the range of the piston stroke. From the power efficiency point of view this construction is optimal only for movement with full stroke and maximum load (Fig. 3.).

As mentioned before, the conventional cylinder means great cylinder volume and accordingly inconveniences in the form of unfavorable gas consumption and low stiffness characteristics. These troubles can be mastered partly by means of a more complicated motor construction (several cylinders in serie or parallel arrangement). However, here only the conventional cylinder motor is dealt with.

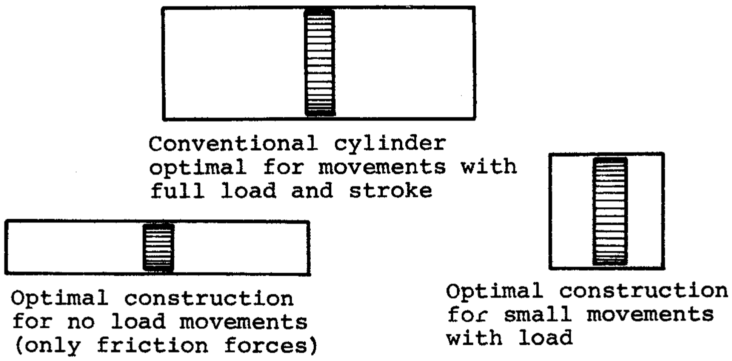

Fig. 3. Different form of cylinders

Pneumatic System

A valve controlled system is of interest. Two conventional possibilities are shown in Figure 4.

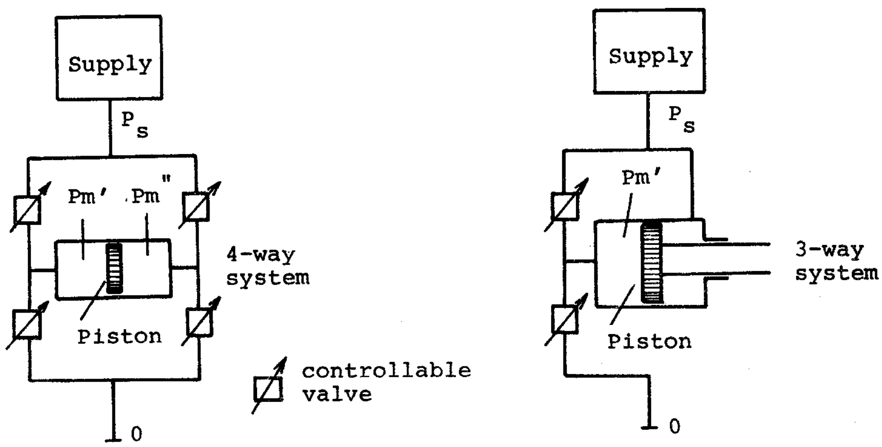

Fig. 4. Principles of 4-way and 3-way control

A three-way system can give a more simple valve arrangement; only two orifices are involved. When the same maximum force is technique. A locking device is probably necessary in prosthetic applications due to the great power loss in a stalled motor. Velocity and force feedback are often desired. The weight is approximately directly proportional to the output power. This makes electric systems suitable for low and medium sized servos.

An electromechanical servo has the following relative merits:

Positive:

(a) Simple and well known system;
(b) Simple control;
(c) Low weight at small and medium sized systems;
(d) Good dynamic performance;
(e) Small and easy-to-use rechargeable battery.

Negative:

(a) High weight of system and supply at great power;
(b) High power losses at low velocity;
(c) Noisy.

Comparison

The choice between different systems is a very delicate job, and will not be treated in detail here. It is certainly dependent on the specific application, available components, and many other things. A simplified reasoning on the power efficiency of the driving system could, however, be of the same value. If the F-ω-diagram shown in Figure 6 is used, the specific command signal U, shown in Figure 7, is obtained.

In order to make an appropriate choice between different driving systems it is necessary to have at least an approximate feeling for the output range that is the movement pattern of the prosthesis/orthosis. If, for example, movement with a small load is dominant the valve regulated hydraulic system is very inefficient and the same goes for the electric system when small velocities with big loads are common. The efficiency of the driving system, of course, will influence the weight of the supply. The weight of the driving system is very much dependent upon the output power, big output power being in favour of pneumatic and hydraulic systems. Many other important things will now influence the choice, e.g. the dynamic performance, the need for a lock, the cost and complexity, available components, etc. A very important thing is the kind of supply that will be needed. The weight, cost, and interest. Acceptable dynamic performances are probably rather easily obtained. Valve regulated systems have rather poor power efficiency. The supply must normally contain battery, motor, pump and accumulator. The weight of the energy supply source can then easily be critical for prosthesis applications.

Hydraulic systems seem to have the following relative merits:

VALVE REGULATED

Positive:

(a) Low weight/hp for the system, especially for high power;
(b) Small energy losses at small movements;
(c) The same supply can feed many systems;
(d) Very good dynamic performance. (Locking at zero command signal is automatically obtained);

Negative:

(a) Poor power efficiency (except when the load is not moving),
(b) Rather heavy and expensive supply;
(c) A latent risk of oil leakage.

PUMP REGULATED

Positive:

(a) Low weight/hp for the system, especially for high power;
(b) Good dynamic performance;
(c) Good power efficiency for the system;

Negative:

(a) Rather expensive supply;
(b) Separate supply is needed for every system;
(c) A latent risk of oil leakage.

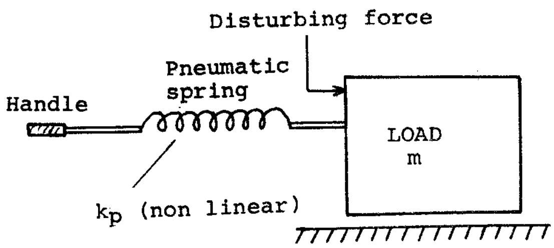

Fig. 5. Simplified model

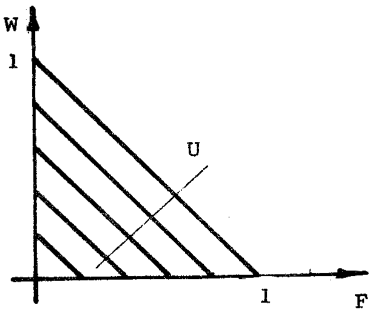

Fig. 6. Characteristic diagram

Electrical System

Designing electromechanical systems is an old and well known complexity are, of course, important as is the problem of re-charging.

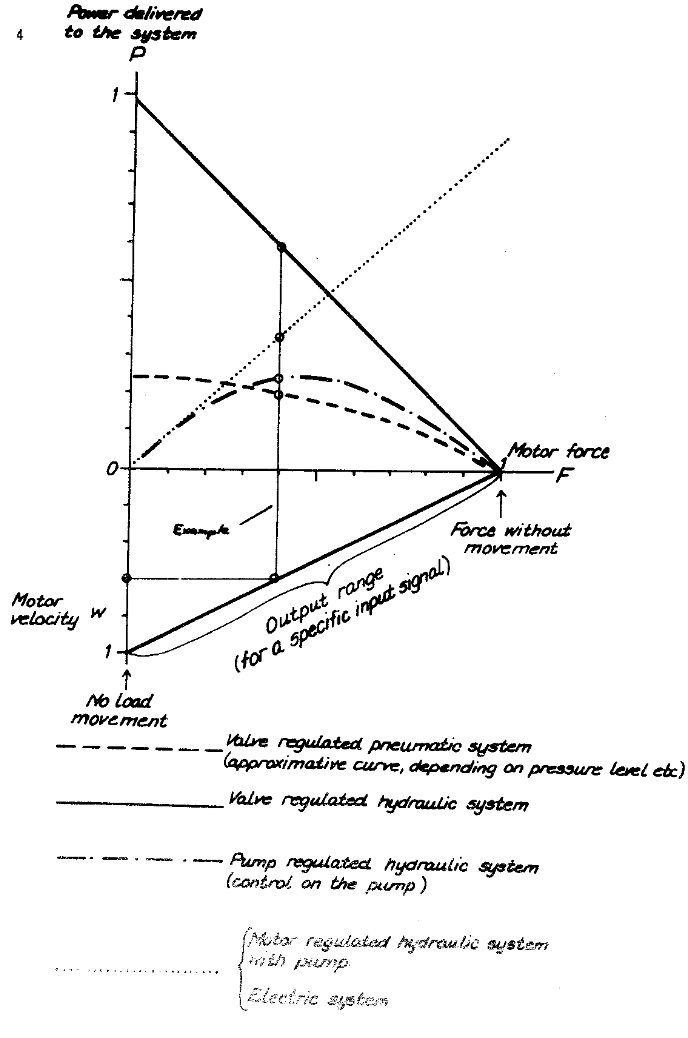

Fig. 7. Diagram, useful for comparison of the power efficiency of different driving systems

References

/1/ Ulén, E. and Wager, M.; "Driving Systems for Orthosis/Prosthesis Applications," FOA 2 Report C 2477-54, June 1971.