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# THE AMOLL PROJECT
(Active modular orthosis for lower limbs)

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## INTRODUCTION

Human gait is one of the most sophisticated systems of locomotion existing in the animal kingdom. It is made up of two essential functions. (1) propulsion : a sequence of gait cycles permitting displacement, and (2) dynamic stabilization permitting balanced upright posture over rugged terrain, as well as acrobatic positions.Sequential movements acquired at a young age, are automatic functions, which are under the voluntary control of the hierarchical command system and so permit the choice of starting, stopping, the path and the speed of walking. In order to maintain dynamic stabilization we must constantly utilize sensory feedback. This feedback comes from vision, the most precise system of regulation (visual control), from the cutaneous zone of contact with the ground (exteroceptive level), from the modular and tendinous sensors (proprioceptive level), and from the vestibular inertial center (semi-circular canals, sensors of linear and angular acceleration ).

For many disabled people, particularly paraplegics, polio patients, those with congenital deformities of the lower limbs or polyneuritics with a loss of the gait function, or in aged or cardiac patient, a certain deficiency of gait function, some compensation is required : either the use of crutches, which if the upper limbs are functional, permit a pendular gait, or 4 cycle gait ; or the use of a wheel chair, either manipulated by the patient himself, or run by electrical motors. Whatever methods used the patient cannot walk normally.

The principal objective of the AMOLL project is to restore the function of locomotion by an active orthosis. It is certain that the large number of people working on this project is highly justified because the difficulty of the problems to be solved call for interdisciplinary collaboration. The purpose of this paper is to take stock of our research and to present the essential elements of the project.

There are three kinds of problems to be taken into consideration :

1) the conception of an orthosis and its adaptation to the patient,
2) the problems of portable energy and the choice of actuators,
3) the control problem.

## PROBLEMS IN DESIGNING THE ORTHOSIS

There are two main requirements : it must be handy and comfortable for the patient and of a reasonable weight. If the patient is to accept and use his assistive device, it is essential that it be as simple as possible. We have chosen an orthotic suit composed of three modules, permitting adaptation to each part of the impaired limb. The modules which are attached to the pelvis, thigh and lower leg are joined together by two articulations, one on the hip and the other on the knee. When assembled, the modules constitutes a pneumatic-metal composite system to hold the motors next to the corresponding joints, metal pins are placed between pneumatic tubes fixed in the suit (figure 1). This pinching effect when the tubes are inflated gives a good attachment and relieves the strain on the metal pieces.

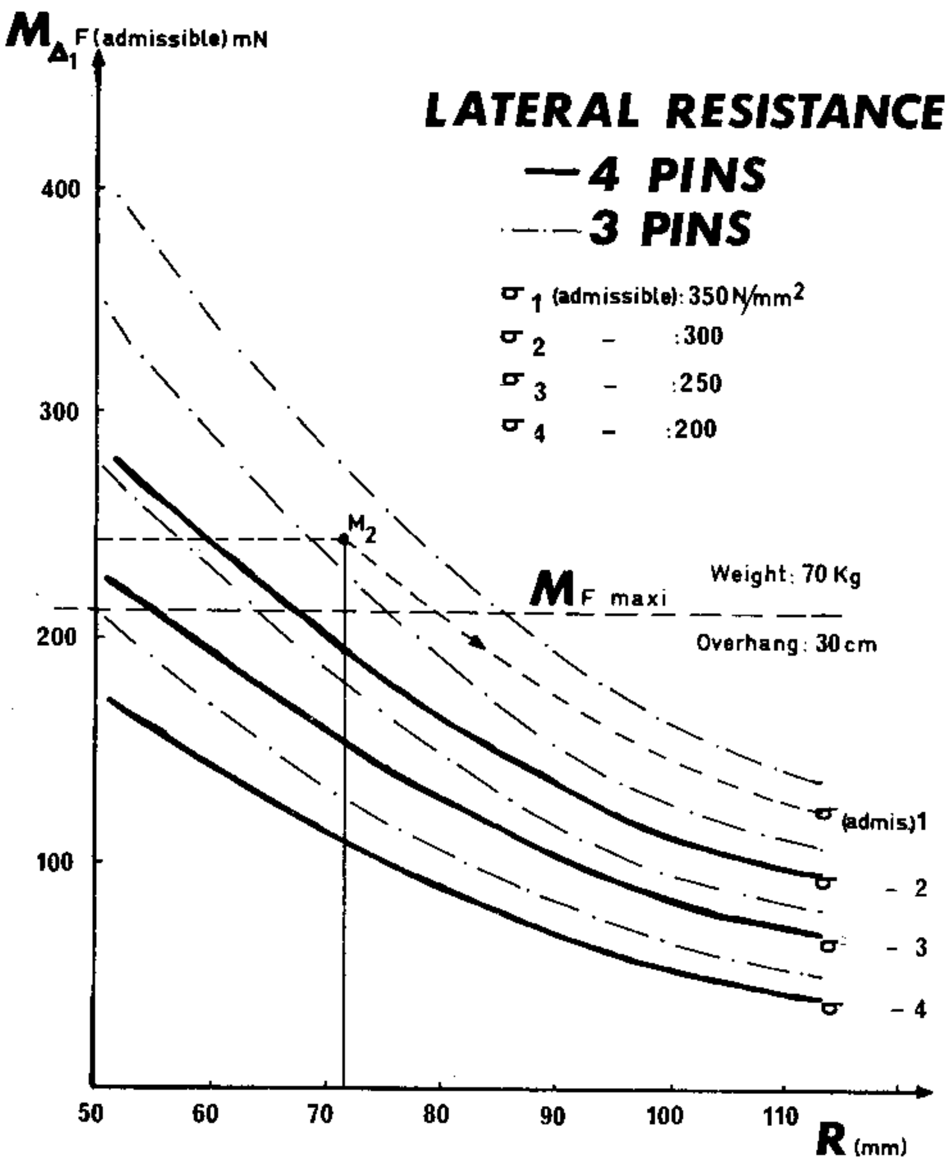
First of all the mechanical efforts at the metal-pin and pin-holder levels were measured laterally and anteroposterially, for a 3 pin or 4 pin system. (Figure 2) and(figure 3) . The pneumatic composite was also mechanically measured, the combined results are shown in table 1. One sees that the composite system diminishes the strains and that the patients limbs carry a part of the load. The second result implies that the patients limbs

Fig 1 - Modular thigh unit with rods in place.

can support the loading efforts. Another advantage of this modular system is that compared to the one-piece pneumatic orthosis used by paraplegics, it is no longer necessary to inflate and deflate the orthosis to stand up or sit down. Figure 4 shows the assembled modules.

TABLE 1 - Mechanical tests on Pneumatic suit.

| | flexion. max N/mm2 | torsion max N/mm2 |
|---|---|---|
| Only metal-pins suit deflated | 510 | 525 |
| Metal pins with pneumatic pinching effect (press.2 bars) | 380 | 400 |
| inflated suit on limb | 140 | 280 |



$M_{\Delta_1}$ F (admissible) mN
LATERAL RESISTANCE
— 4 PINS
-·- 3 PINS
σ 1 (admissible): 350 N/mm2
σ 2 – : 300
σ 3 – : 250
σ 4 – : 200
400
300
200
100
M2
M F maxi
Weight: 70 Kg
Overhang: 30 cm
σ (admis.) 1
σ – 2
σ – 3
σ – 4
50
60
70
80
90
100
110
R (mm)


Fig 2

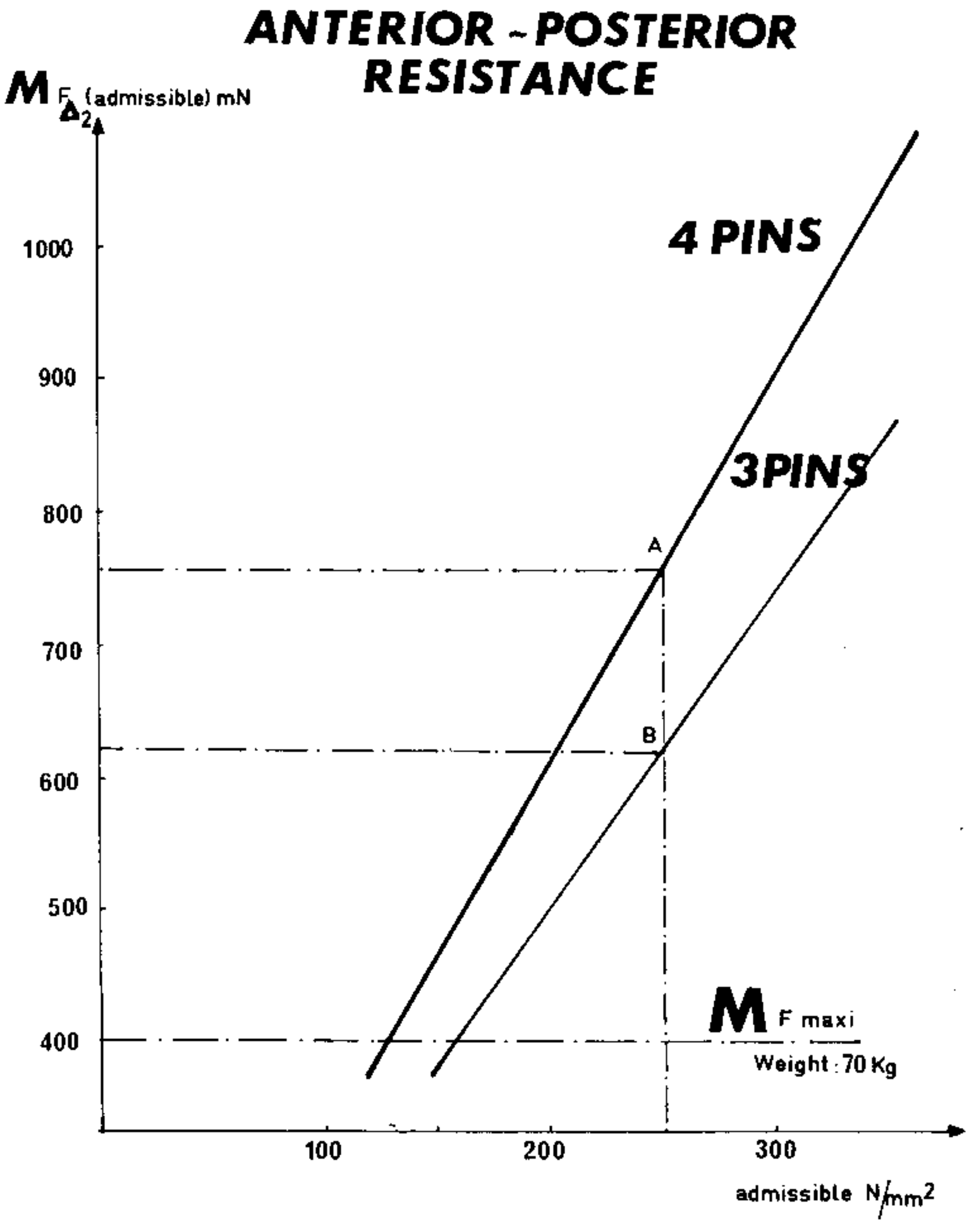

ANTERIOR - POSTERIOR RESISTANCE
M F Δ2 (admissible) mN
1000
900
800
700
600
500
400
4 PINS
3PINS
A
B
M F maxi
Weight : 70 Kg
100
200
300
admissible N/mm2

Fig 3

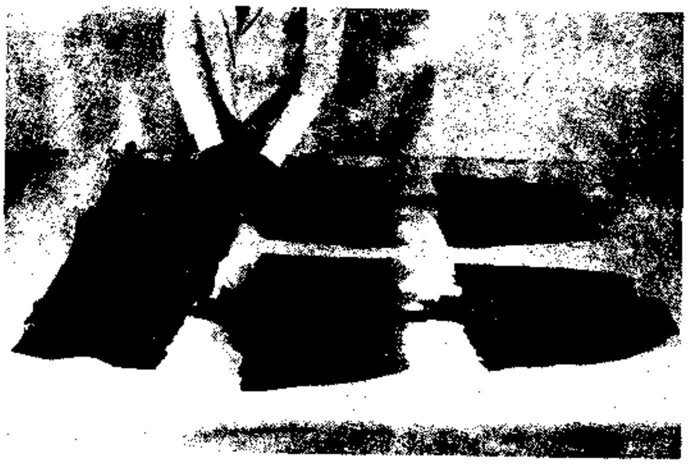


Fig 4 - Modular assembly

This arrangement permits a simple mounting of the orthotic device on the patient.

PROBLEMS OF ENERGY AND THE CHOICE OF ACTUATORS

The calculation of the energy necessary for the two-legged locomotion, has been the object of numerous works. The most recent being those of Yukobratovic and his team (references 1 and 2). Even though we lack precise experimental data, we think that an orthotic suit needs power of 250 watts. The choice of energy is not yet definitely decided. Electrical energy is easily stored but the possibility to obtain a free, passive, state, a blocked state and powered movement in two directions can only be made with a connecting gear or with torque motors. Our choice seems to go towards the use of D.C. servo motors with a nominal power of 60 W for the hip and 30 W for the knee. These motors have a peak power to average power ratio of 4 to 1 compared to only 2 to 1 for torque motors. Rotatory hydraulic actuators pose problems of fluid leakage and energy storage ; but it is easy to have high power with a lower weight and to have three states of control (powered, free, and blocked).

However, the source of portable energy will be the aim of special research. It should allow an autonomy of 1 hour without outside support.

We have voluntarily chosen only 4 actuators even though this poses a double problem : what to do with the passive degrees of freedom and the movements at the foot. Indeed, each mobile articulation only has one active degree of freedom. In the case of the hip, there are normally three degrees of freedom that serve the orientation of the lower limb. We have therefore, undertaken to reduce the lateral motion and the torsion to its minimum to have a more rigid orthotic system. The knee being a rotary joint requires only one active degree of freedom. We treat the foot in the same way as the lower limb prothesis. The mobility of the ankle joint will be reduced to a few passive degree of freedom. Walking in this case, will be possible due to a special shoe, with a anterior and posterior curved sole and a square heel, so that the foot will be pushed in a good position as soon as the heel contacts the ground.

## CONTROL PROBLEMS

Control problems are the most difficult of all. Two solutions are possible : in the first, the patient is placed in an entirely automatic system which includes propulsion and stabilization. In this case, the major risk is that he feels "foreign" to his device, and ill at ease with it. In the second case, the patient takes care of the stabilization, himself, propulsion, and regulation of gait being provided by an artificial system. We have chosen the second solution, for we feel that the patient accepts an assistive device more easily if he himself is responsable for his stabilisation using two crutches (see figure 5).

The control system for propulsion must be a logical system. The different states are detected from the contact information of the heal and toe with the ground and angular information from the hip and knee joints. Preliminary, measurements made on a treadmill show that the curves of angular speed as a function of the normalized time in the walking cycle are independent of the walking speed and angular speed at the joints. For a given subject the peaks occur at the same point in the cycle. In addition both the length of the step and the cadence are proportional to the walking speed ; the curves having almost constant slope.

Theoretically this permits an automatic control of the walking sequence in order to minimize the energy used and to adapt the force of the motors to possible variation of passive joint resistance (cases of spasticity in paraplegics) a system with automatic feedback to limit the torques.

The patient able to intervene in the logical programme, with the help of switches for the hierarchial control of the following four parameters

A. start

B. standing up : sitting down

C. speed control. This is carried out in two ways.

1) either changing the length of the stop
by controlling the extent of the angles or

2) changing the rate of stepping.

Eventually the combination of the two procedures can be controlled by a single command.

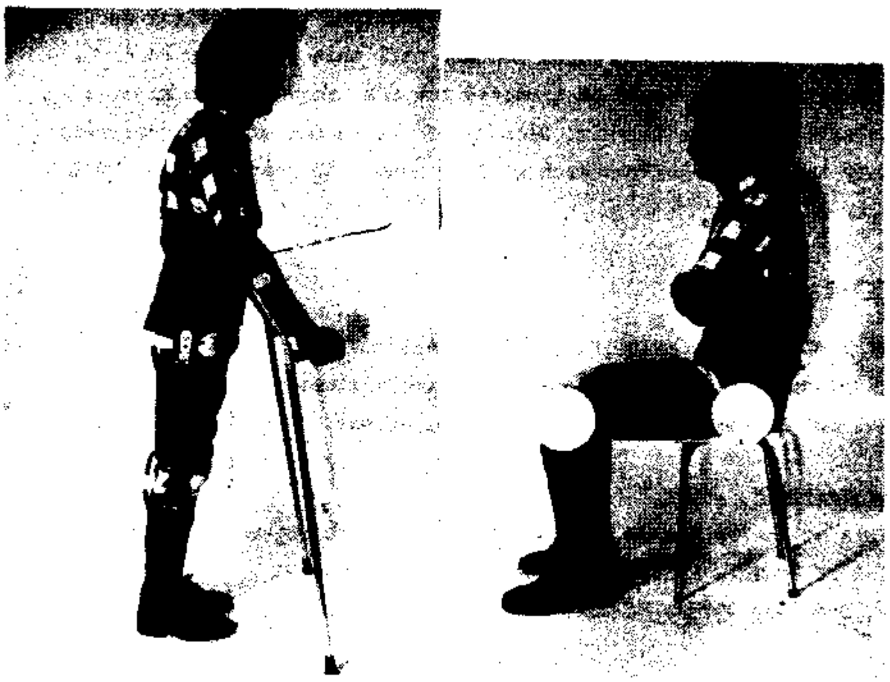


Fig 5 -Subject standing with crutches and sitting. In standing position(left)the subject wears a prototype suit with passive joints. In the sitting position (right) mock-up rotary hydraulic actuators are mounted on the joints.

D. Stop. (Two types are probable)

1) preprogrammed stop - when anticipated, the system can be brought to a stop slowly within a few steps, with feet together at the end of the sequence.

2) Emergency stop. - either the feet are quickly brought together, or the joints are put in the free state if a fall is inevitable.

With this man-machine control system for walking, the principal decisions are made by the patient. Medical doctors call this voluntary control. The future research should be directed towards programmes to mount steps and to walk on uneven terrain. Because of the amount of work necessary, probably three years of research will be needed to complete the AMOLL project.

REFERENCE

M. VUKOBRATOVIC, D. HRISTIC, and Z. STOJILJKOVIC, -
"Development of active anthropomorphic exoskeletons",
Medical and Biological Engineering, pp66, January 1974.

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Analysis of Energy Demand Distribution within Anthropomorphic Systems"
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