# HYBRID POWERED ORTHOSES

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## ABSTRACT

The feasibility study on Hybrid Powered Orthoses (HPO) is presented in this paper. HPO comprises active external brace in parallel with functional electrical stimulation (FES) application for gait restoration of handicapped's. Such an combination is assumed for indications where the FES is not adequate and/or effective. Partial energy concept is intoduced for the self contained assistive device purpose. Papers presents pioneer result on gait restoraton of complete paraplegic patient by means of HPO.

Keywords: Hybrid system, Active brace, Artificial reflex,Paraplegic gait

## INTRODUCTION

Experience in use of first developed hybrid systems /1,2/ pointed out the necessity for activation of external brace. Active brace is needed for some functional disabilities because of nonefectivity of FES. Shortly we will mention the main features of hybrid assistive systems (HAS). HAS is parallel application of external brace and FES. The main aim of HAS is gait restoration of handicapped's with thoracal and low cervical spinal lesions. We are using Self-Fitting Modular Orthoses (SFMO) as the brace part of HAS, and surface stimulation as main actuator of the HAS. Control strategy is based on artificial reflex loops /3,4/.

This paper presents the feasibility study of the HPO use. Two objective criterions for eficiency of HPO in comparison to the components of the system are introduced, i.e. we are trying to reduce ground reactions through arms and to reduce metabolic energy consumption regarding the 'normal' gait pattern. Subjective criterions which we assumed important are variety of gait patterns, patient physiological and psyhological acceptance, safety and reliability.

The central feature of adopted HPO is the hardware and software openess. We use the term openess to express the flexibility and modularity of HPO. Modular design, self-fitting and self-adjusting of SFMO as well as all possible combination of FES allows us to apply any desired combination just by adding or taking out necessary parts. Knowledge based control algorithm can be easily modified for any hardware combination. The expert system is generally created allowding realisation of different artificial reflex actions.

As it is mentioned, the aim of active brace lays in the medical indication. The number of paraplegics are not appropriate just for FES because of the functional status of the neuromuscular system or some other functional disorders as well as muscle fatigue /4/.

HARDWARE FOR HPO

In this paper we are reffering to HPO with externally controlled and powered SFMO. SFMO with externally controlled locking device /2,5/ is modified through the integration of cybernetic actuator /4,6/ into the knee joint.

Cybernetic actuator is developed and tested in active A/K prostheses. The original prosthetic motor unit is redesigned in order to allocate electrical motor and brake mechanism from the knee joint.

Cybernetic actuator is designed by the use of cable driven ballscrew attached to the knee joint modul of the SFMO (Fig 1).

Motor unit is attached to the patient's back. The characteristics of motor unit are: helicoidal step h=2.8 mm, $P_{max}$=38W, n=5000 rpm, tr=16 ms, $\eta$=81%, m=300 g. The characteristics of the brake unit are: drum brake with asbestum lining $\mu$=0,72, $P_{max}$=3,5W, n=9500 rpm, $\eta$(reduction)=97.3, t(on-off)=12 ms, m=120 g.

The FES is realysed with surface stimulation /10,11,12/. We are controlling pulse amplitude and pulse width over µcomputer. We are using monophasic stimulation with frequence f= 20 Hz. The exponential rise and fall time are introduced in stimulation sequencies in order to decrease jerking. The stimulator is with four independent channels with pulse regulation from 200 µs to 2 ms, and 20 mA to 120 mA. It is constant current stimulator. The frequency can be changed from 15 to 50 Hz, prior to use by the medical stuff.

Sensory feedback is restricted to insole switches and potentiometers in the knee joints. The simple ground level gait is chosen for preliminary studies because of the complexity of the HPO and disorders of the nervous system of our patient

Controller is based on Intel 8085 µprocessor including clock, A/D and D/A converters, I/O port, ROM (64 K) and RAM (64K) and it is connected to the driver unit with eight independent channels.

System is powered with NiCd rechargable bateries (18 V).

It is to be seen that the proposed system is self contained. The over all weight of components is in the range of 65 N, and through testings on the computer terminal device the battery package is estimate to last for 2,5 hours of the gait.

Hand supports over crutches or canes are absolutely needed for maintaining of ballance.

## CONTROL ASPECTS ON HPO

The HPO is very complex system. It integrates residual volitional motions, externally stimulated motions and external brace action. The mathematical , i.e. computer simulation of the system /7/ shows that the numerical control is far away from the real time. In the same time nonnumerical control in medical robotics is our basical approach in regulation of assistive devices /8,9/. Nonnumerical control is based on output space approach which fit exellent in the knowledge system methodology. Originally, knowledge system, as well as most other expert system techniques are developed in order to solve cognitive problems (war games, diagnostics etc.).

The artificial reflex control is an attempt to include knowledge system in the movement control /13,14/. First experiments in the regulation of the A/K prosthesis pointed out that the actuator level needs a portion of dynamical control, or the very appropriate hardware. When prosthesis is considered, there is no doubt, that design procedure can include adequate technology and specific elements (nonlinear limiters, springs etc.). When orthosis is the goal, most of the system variables are almost stohastic and there is no way to determine them in advance (spasms and the like) which imposes the software flexibility and adaptivity. These facts proves even more that the use of expert system methodology , specificly production system which is sensory driven is the appropriate one.

The concept of the control, which is really in the first phase of development, is based on gait synthesis as sequence of events (states in the output space). Sequencies are built int the data base. Production rules are stored as well into the data base. When desired locomotion activity is started corresponding set of states with production rules is transfered (after searching procedure) to the working base. Tracking procedure /15/ is incorporated at the lowest control level to reduce on-off control effects. The most important part in the control design is estimation of parameters for the data base and corresponding production rules. There is no experience in use of HPO, and our knowledge relays only on imagination and computer simulation. The more we learn abouth the HPO the better will be the handicapped's gait. We haven't included learning procedure into the expert system for HPO gait yet.

It is interesting to clerify parallel action of biological (volitional) and axternally controlled movements (FES or active SFMO). The schematic explanation (Fig 2) will be discussed here. To make it more clear we will explain it on example, the knee flexion during swing phase. The actual powering system of the HPO are muscles. Muscles are acting because of the FES (total SCI patient). It the terminal angle is not achieved, and the angular rate decrease to zero value, the external motor unit is turned on. If in the time limit the desired finite state is not acieved the action will be stopped. If the desired position is reached the actuator is turned off and muscles are again the only powering part.

In the same time in all locomotion phases where muscles are working in isomorphic conditions the orthoses brake mechanism takes over the action and muscles are resting (for example the stance phase in stable standing).

Table I presents the element from the data base for HPO.

## RESULTS

Preliminary tests has been carried in the Rehabilitation Centre 'Dr Miroslav Zotović' in Belgrade.

M.N., 23 years, male, scul fracture and traumatic lesion of the spinal cord after fractured of the Th7 vertebrae. On the December, 1. 1986. treated surgically after two weeks by decompression of the vertebral body.

Neurologic status: Complete paraplegia below Th7 level.

Functional status: walking in parallel bar for 10 minutes, poor control with FES of the right leg. Combination of SFMO and FES (HAS): four point gait could not be achieved because of inadequate response of the right leg to the FES. The HPO is the system which we assumed to give better gait pattern to the candidate. Without going into the details of fitting and learning how to use the system we will explain some of the objective results.

We measured the energy consumption and ground reactions (legs and arms), gait speed and range of movements. We teached the patient to use properly, as good as possible, the HPO and we analysed subjective criterions, such as muscle fatigue, skin pressures, acceptance etc. For measuring we are using strain gauge sensors on the crutces, force plate, goniometric system and oxygen consumption.

Maximal registered gait speed were:

v(SFMO)=0.6m/s, v(FES)=0.5m/s, v(HPO)=0.74m/s.

We will present in this paper only angular changes obtained in use of HPO in comparison with SFMO and FES (Fig 3).

We will mention that we observed tremendous decrease in energy consumption comparing external brace and FES or HPO. There is no big difference between FES and HPO use. The bigest difference is the muscle fatigue on the quadriceps in HPO versus FES application.

One of observations we made is the efficiency in arm ground reaction decrease in HPO application. The efficiency rises up with the growth of the gait speed. The energy expenditure decrease as well with the gait speed growth. These facts are to be expected because inertial forces are included when gait 'dynamics' instead of 'quasi statics' is achieved.

## CONCLUSION

The research goal in the design of assistive devices for gait restoration is the acceptable system which will reduce the use of the wheel chair. The efficiency of simple brace as well as the gait mode is rather poor. The use of FES is restricted with numerous factors among which we will point out muscle wheekness, denervation, fatigue etc. The number of thoracal and cervical lesions in SCI are not approapriate candidates for the stimulation.

In order to overcome some of the disadvantages of mentioned orthotic devices the HPO with active brace joints is introduced. The main contribution of the HPO is the involvement of additional partial energy to the externally initiated functional movements through FES. In the same time external brace introduces safety and reliability as well as reduction of muscle fatigue.

Applied control algorithms are primitive version of an expert system. The design of the hardware and software allows any desired spreading of the HPO including learning capabilities. Production rules are obtained by modification of rules applied for prosthesis control. One of the shortcommings are artificial sensors which are not quit reliable, because of fitting and positioning.

We posed the criterions on the efficiency through magnitudes of ground reactions over arms, energy consumption and angular displacement of joints. The gait speed is the very important parameter for efficiency as well. The subjective goal has been reached better with HPO, then with the HPO components application (psyhological acceptance,reliability, safety, etc.).

Preliminary tests are proving the advantage of HPO to the components builted into the system (SFMO of FES) in individual use. The complexity of the system including price, maintenance, training of P.T.-s and patients, reliability and the like imposes further research in externally controlled hybrid assistive systems. The described assistive system is the first combination of externally powered brace with the stimulation in order to restore locomotion.

## ACKNOWLEDGEMENT

This work is partly supported by NIDRR, Washington, D.C., and partly by Research Community of Serbia,Belgrade,Yugoslavia

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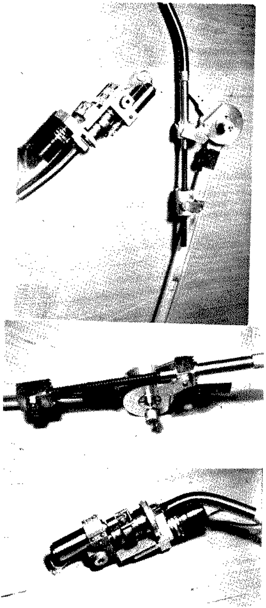
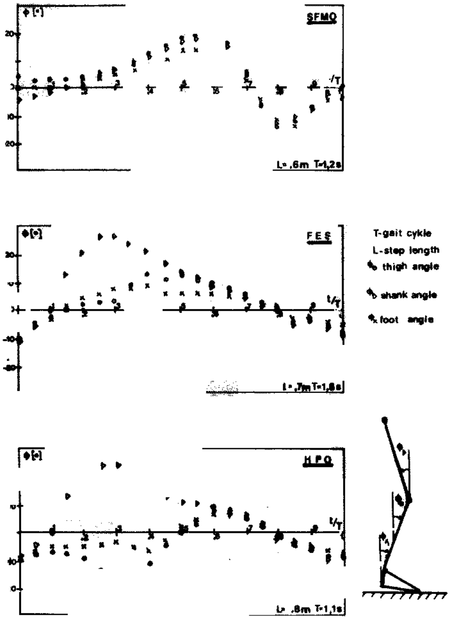


Cybernetic actuator for the Hybrid Powered Orthosis

Ballscrew attached to the knee modul of the SFMO

Motor and Brake unit for the Hybrid Powered Orthosis

Figure 1.


Φ[°]
SFMO
L=,6m T=1,2s
t/T
FES
L=,7m T=1,6s
T-gait cykle
L-step length
Φ thigh angle
Φ shank angle
Φ foot angle
HPO
L=,8m T=1,1s

gu

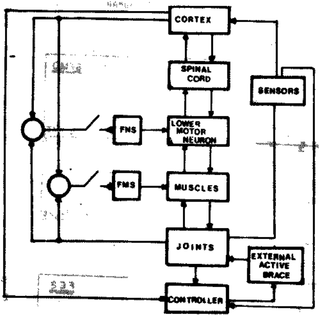
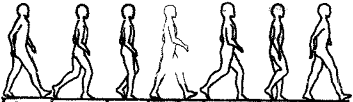



Figure 3.

L - left foot
R - right foot
S - stimulation
M - motor actuator
B - brake
F - flexion
E - extension



| | HEAL STRIKE | | | GAIT CYCLE | | | HEAL STRIKE |
|---|---|---|---|---|---|---|---|
| LSF | 0 | 1 | 1 | 0 | 0 | 0 | 0 |
| LSE | 1 | 0 | 0 | 1 | 1 | 1 | 1 |
| RSF | 0 | 0 | 0 | 0 | 1 | 1 | 0 |
| RSE | 1 | 1(0) | 1 | 1 | 0 | 0 | 1 |
| RMF | 0 | 0 | 0 | 0 | 0(1) | 0(1) | 0 |
| RME | 0(1) | 0 | 0 | 0(1) | 0(1) | 0(1) | 0 |
| RB | 1(0) | 1(0) | 0(1) | 0(1) | 0 | 0 | 1(0) |

Table 1.