POWER FOR ARTIFICIAL ARMS FROM NORMAL WALKING*

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Abstract—Several pumps mounted on the shoe were constructed in order to evaluate their potential as a power source for artificial arms. A variable stroke pump was used to determine the effect of different stroke lengths on the power available and on the gait of the subject. A stroke of 9 in. (9.5 mm) was found to be near the optimum and to produce adequate amounts of power. Prototype pumps utilizing this stroke performed satisfactorily.

INTRODUCTION

The commonest power systems for artificial arms are battery driven electric motors and pneumatic actuators employing carbon dioxide stored in the liquid phase in a portable high pressure cylinder. Electric motors tend to be heavy and noisy with a high inertia, while CO₂ cylinders require frequent recharging at a central point which is most inconvenient to the patient (see LAMBERT and HALL, 1968; SIMPSON, 1968).

A self-contained system, independent of external power supplies would be a great advance. Such a system was outlined by one of the authors, McLEISH (1968), who carried out a design study on a system using reciprocating hydraulic pumps mounted in the heels of the shoes to pressurize a hydraulic accumulator (see Fig. 1). The hydraulic pressure would be used to actuate an artificial arm similar to the pneumatically powered arms currently in use. The pump proposed has too short a stroke to compress gas to useful pressures but this is not thought to be a disadvantage since there is a lot of evidence (LAMBERT and HALL, 1968; STEVENSON and LIPPAY 1968; CHAPMAN, 1969) that hydraulic systems respond more quickly and are stiffer and more stable in operation than pneumatic systems.

In order to investigate the feasibility of such pumps, two types of pumps were constructed, a variable stroke experimental pump and a pair of prototype pumps suitable for more prolonged use. The pumps were designed for normal use at a pressure of 500 lb/in² (3·42 MN/m²), as previous work, McLEISH (1968), had shown this to be desirable, but any of the pumps could produce a similar performance at other pressures by modifying the piston area.

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VARIABLE STROKE PUMP

This pump was intended to investigate pumping forces and strokes and any device which produced forces similar to a pump would have served the purpose. A hydraulic pump, unlike a pneumatic pump or a spring, requires full force throughout its stroke and, as no simple device has this characteristic, it seemed best to make a variable stroke pump which would charge a hydraulic accumulator whose pressure could be varied to alter the pumping force.

As long strokes were required it was necessary to mount the pump outside the heel to avoid excessive heel depth, but the ground contact force had to be kept in line with the heel. To achieve this the pump was mounted behind the heel as shown in Fig. 2 and operated by a simple lever system. Variable strokes were achieved by inserting packing washers on the pump shaft to limit its stroke. A \( \frac{3}{8} \) in. (9.5 mm) ram diameter was chosen to give a fluid pressure force of 55 lb (245 N) at the design pressure of 500 lb/in\(^2\) (3.42 MN/m\(^2\)). The lever arms used gave a calculated force at the heel of 68 lb (303 N) but with friction and spring effects the actual force was 76 lb (338 N). The pump was returned by a light spring within the cylinder and flow was controlled by two spring loaded ball type non-return valves mounted above the pump.

Initially tests were carried out on subjects ranging in weight from 112–182 lb (500–810 N), using the maximum pumping force of 76 lb (338 N). The maximum stroke available was 1 in. (27 mm) giving a movement in line with the heel of \( \frac{2}{3} \) in. (22 mm). Although all subjects could operate the pump at all strokes, varying degrees of difficulty were experienced. With short strokes, all subjects could operate the pump easily, rapidly becoming unaware that they were pumping. On the other hand with light subjects and long strokes, it was necessary to keep the weight on the heel for unusually long periods making normal gait quite impossible. The length of stroke which each subject would accept clearly varied with his weight and each subject was asked to assess the maximum stroke which he considered acceptable for long term use. This judgement was made after a short period of familiarization. Further tests were carried out on three of the subjects at reduced pressure and in every case longer strokes were found to be acceptable. The results of all tests are shown in Table 1.

The acceptable pumping force \( P \) should be proportional to body weight \( W \) so that the results can be used to determine the way in which \( P/W \) varies with heel movement. This ratio is plotted in Fig. 3a where the test points show a clear trend. If this trend line is now applied to