Foot-force measuring device for clinical assessment of pathological gait

S. Miyazaki
Institute for Medical and Dental Engineering, Tokyo Medical and Dental University, Chiyoda-ku, Tokyo, Japan

H. Iwakura
School of Medicine, Teikyo University, Itabashi-ku, Tokyo, Japan

Abstract—A portable device has been designed, constructed and tested which measures continuously the vertical component of the forces exerted by the foot during walking. The device consists of two pairs of force transducers, an amplifier-transmitter unit, and a receiver-processing unit. A pair of force transducers are attached to the soles of a pair of sports shoes at the metatarsal region of the heel. The transducers are relatively thin (6 mm) and light (65 g) so that they hardly interfere with the patient's customary walking style. The signals detected by the transducers are amplified, f.m. telemetered, and summed to give the total force acting on each foot. The amplifier-transmitter unit worn by the patient weighs about 180 g and measures 105 x 80 x 23 mm. The performance of the device is tested by comparing the output of the device with that of a conventional force plate. The device is found to be accurate enough for its intended use for the clinical assessment of pathological gait.

Keywords—Foot force, Locomotion disability, Measuring device

1 Introduction

Quantitative measurements of the gait will greatly facilitate the objective assessment of lower extremity defects in orthopaedic patients. They would also be useful for evaluating past treatments and for providing information for further training in rehabilitation clinics.

Various kinetic, kinematic, and electromyographic methods have been employed to monitor the gait (Winter, 1976). One of these is to measure the forces acting between the foot and the floor during walking. Characteristics of the foot-force patterns in normal and pathological gait have been reported (Saunders et al., 1953; Jacobs et al., 1972), and the usefulness of the foot-force measurement has been indicated.

At present, the most commonly used devices to measure the foot forces are force plates, which are mounted in the walking floor (Cunningham and Brown, 1951). Although very accurate, force plates are only large enough to measure the foot forces occurring during a single step. The subject has to pace his walk to place his foot correctly on the force plate, which is, in itself, a limitation on free walking. In addition, force plates are not portable, and they are rather too expensive to be used clinically.

The alternative method for measuring the forces exerted by the foot is to attach force transducers to the subject's shoes. Several instrumented shoes have been developed for this purpose (Spolek et al., 1975; Levin et al., 1976; Nagi et al., 1976). None of these instrumented shoes, however, have been used successfully as a clinical tool because of poor accuracy and complicated operational procedure. Another serious problem in these instrumented shoes is that the customary walking style of the subject is apt to be altered by bulky transducers. Recently, a clinical experience with an instrumented shoe system has been reported by Hargreaves and Scales (1975), but the technical details are not described.

In this paper, a new device is presented which continuously measures the vertical component of the foot forces unobtrusively. The device consists of thin and light-weight force transducers attached to the sole of the shoe, an amplifier-transmitter unit, and a receiver-processing unit. The design, construction and test results of the device are described below.

2 Description of the device

2.1 Principle

Any foot-force measuring device for clinical use must:

(i) measure the static and dynamic foot forces of each foot separately and continuously
(ii) impose the minimum restraint, either physical or psychological, on the natural walking style of the subject

(iii) be portable

(iv) be simple to operate

(v) be reliable

(vi) be relatively inexpensive

To meet these requirements, it was decided that the present device should measure only the vertical component of the foot forces, which is of the greatest clinical importance among the three mutually perpendicular components of the foot forces.

The principle of the device is briefly explained as follows: Two force transducers are attached to the sole of the shoe at both the metatarsal part and the heel (they will be called the front transducer and the rear transducer, respectively). If these two transducers are arranged in such a way that the forces exerted by the foot are transmitted to the floor only through the transducers, the foot forces can be continuously measured merely by summing the outputs of the two transducers.

2.2 Force transducers

The structure of the force transducer is shown in Fig. 1. The main part of the transducer is a rectangular stainless-steel plate ($t = 1.2 \text{ mm}$). Two supports are attached to the lower surface of the plate at each end. The force applied to the upper surface of the plate causes the plate to bend in a convex downward fashion, resulting in a strain proportional to the vertical component of the force. This strain is detected by a strain gauge fixed to the centre of the plate.

Fig. 2 Front and rear transducers attached to the sole of a sports shoe

The supports are made of neoprene-rubber sponge ($t = 3 \text{ mm}$) and vinyl-chloride sheet ($t = 1.5 \text{ mm}$). In fact, the plate can be supported only by the vinyl-chloride sheets. The functions of the neoprene-rubber sponge are twofold; it serves as a shock absorber, and it minimises the variation of the output of the transducer due to the uneven floor surface, as is shown later.

The dimensions of the stainless-steel plate and the span between the supports may be changed according to the type of the shoe used and the sensitivity required; the wider is the span, the higher is the sensitivity. An irreversible strain, however, may arise from an overload if the span is too wide. Typical values are given in Table 1 for measuring the maximum force of 980 N (100 kgf) using a 260 mm sports shoe.

The front transducer and the rear transducer are attached to the sole of the shoe with silicone adhesive, as shown in Fig. 2. Any kind of shoe with a moderately flexible sole may be used. The authors usually use commercially available sports shoes, which the patients wear in walking practice. The leads from the strain gauges are fixed on the lateral side of the shoe, and are connected with a flexible cable, which runs up along the dorsal side of the leg to the amplifier-transmitter unit fastened about the waist.

To prevent the sole of the shoe from making direct contact with the floor and thus bearing the forces at any instant of the walking cycle, the width of the stainless-steel plates of the transducers, $C$ in Fig. 1, should be relatively large. Excessively large transducers, however, would interfere with the subject's natural gait, since the sole of the shoe becomes rigid. Taking these factors into consideration, the width of the transducers was determined as shown in Table 1. Such transducers allow the

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**Table 1. Dimensions of the transducer plate**

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<th>A</th>
<th>B</th>
<th>C</th>
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<tbody>
<tr>
<td>front</td>
<td>85</td>
<td>55</td>
<td>35</td>
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<tr>
<td>transducer</td>
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<td>rear</td>
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