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INSTRUMENTATION OF A WALKER FOR THE MEASUREMENT OF THE FORCES EXERTED BY THE PATIENT

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ABSTRACT
As part of the project "SHARE – it", sponsored by the VI Framework Programme of the EC, a prototype of Intelligent Walker has been built, to be used as a measuring device to collect information about the interaction between the patient and the walker. One main action are the forces that the patient does to the walker, through the handles. Another important data are the forces that the wheels of the walker do against the floor This Paper presents the design, construction and calibration of the special force transducers used in the handles to separate the three force components, and of the transducers used to measure the reactions of the floor on the wheels.
Keywords: multiaxial force measurement, strain gages, walker**,** mobility help

1. INTRODUCTION
It was decided to build the first prototype of the Intelligent Walker to use it as a measuring device, to collect as much information as possible about the interaction between the patient and the walker. So it was decided to instrument the first prototype to be able to measure the forces of the handles and the forces of the wheels. The forces in the handles can be in any direction, so it is necessary to measure separately the three spatial components of the force on both handles. The forces in the wheels can be only vertical, so only the Z force component is measured at each rear wheel. The 8 force components are measured independently and simultaneously (see fig. 1), and then stored in the on-board computer.

2. THE DESIGN OF THE FORCE TRANSDUCERS
The transducers should fulfill the following conditions: respect the original functional geometry, introduce minimum changes in the structure, allow the simultaneous and separate measurement of the 8 force components, have a static and dynamic response. The type of transducer selected is: strain gage transducers, the material of the body will be steel, the connection of the strain gages will be in full bridge [1, 2, 3].

2.1. X force transducers (handles)
The design of the body of the transducer can be seen in fig. 2. When the X force acts, the body of the transducer is subjected to bending. The strain gages are bonded in the places where the stresses are higher. To optimize the design of the transducer a finite element model of the body has been created and analyzed (see fig. 3). The strain gages are connected in additive full bridge: the signal of the four strain gages contribute with the same sign to the output signal of the bridge (see fig.2).

2.2. Y, Z force transducers (handles)

The Y and Z forces of the handles are measured with the same transducer, but using two separate strain gage bridges. The body of the transducer is a cylindrical tube, subjected through an extreme to an outer tube (see fig. 4). This outer tube is fixed to the X force transducer. When an Y (or Z) force acts on the handle the body of the transducer is subjected to bending. The strain gages are bonded in two separate sections of the body (1-2 and 3-4). The strain gages are connected in a subtractive full bridge: the output signal is proportional to (1+2) - (3+4). With this type of connection the signal is independent of the position of F, and depends only from the value of F (see fig. 5). To measure the Y force the strain gages are bonded in an horizontal plane, and to measure the Z force, in a vertical plane (see fig. 6).

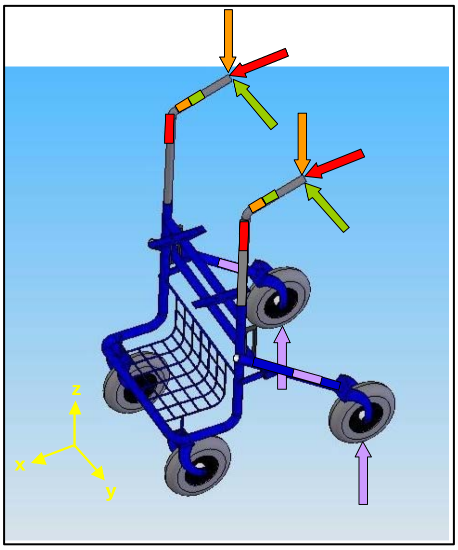


Figure 1. The 8 force components.

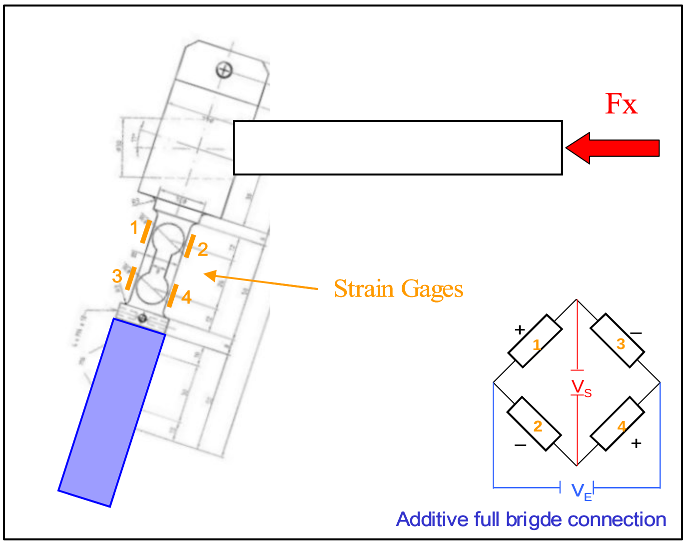


Figure 2. X force transducers

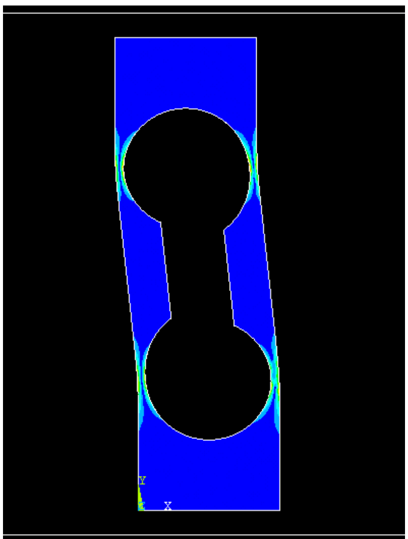


Figure 3. Von Mises stresses obtained with the FE model

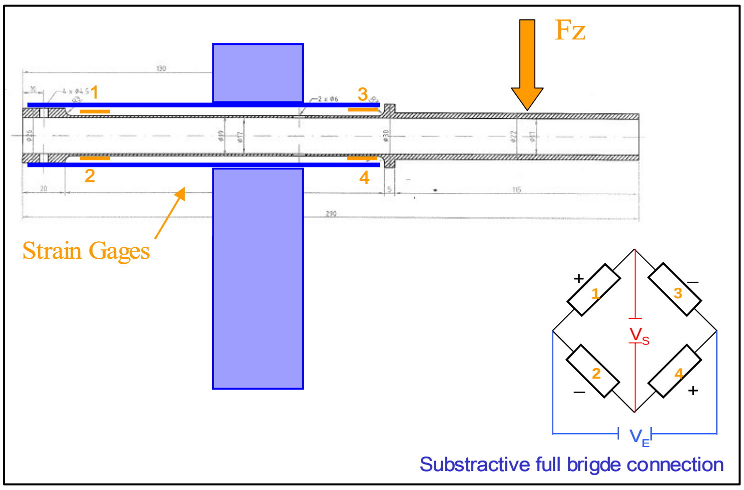


Figure 4. Y – Z force transducer

2.3. Z force (wheels)

The design of the transducer to measure the Z force of the rear wheels can be seen in fig. 7. The body is a cylindrical tube, which substitutes a part of the original tube of the sub-frame of the rear wheels. When the Z force acts (the reaction of the floor on the wheel), the body of the transducer is subjected to bending. The strain gages are connected in an additive full bridge (see fig. 7).

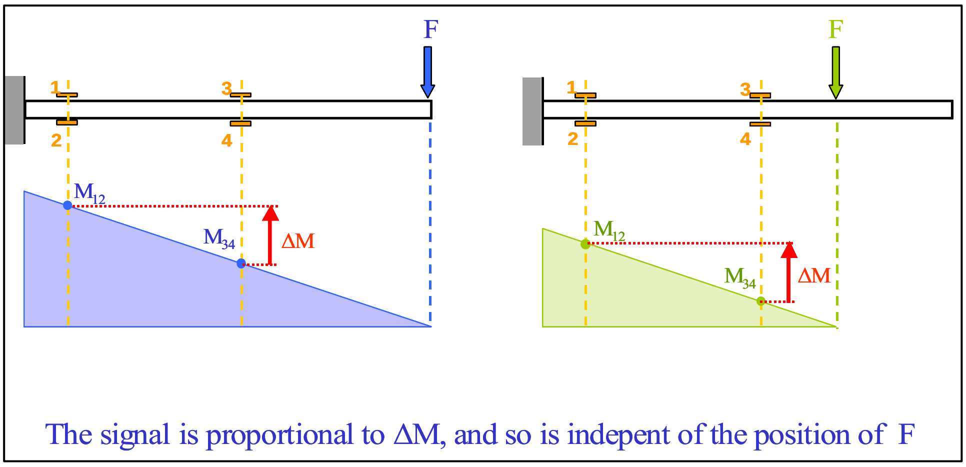
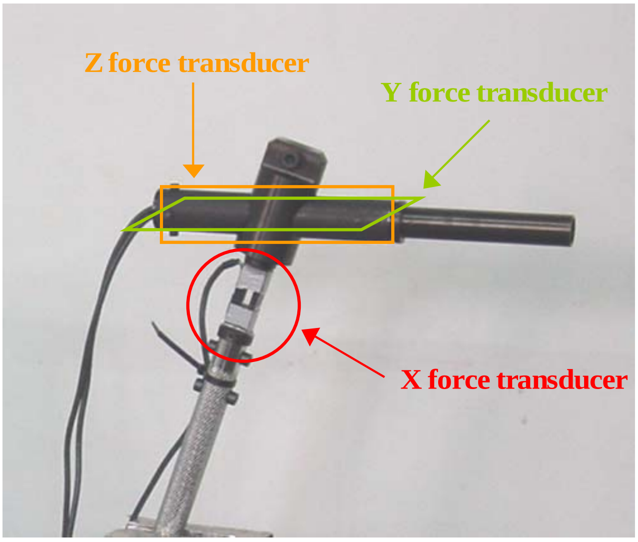


Figure 5. Y, Z force measuring method by difference of moments



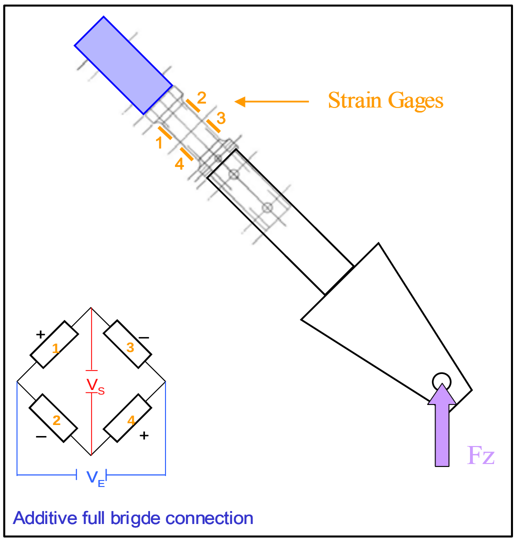


Figure 6. Details of the instrumented handle

Figure 7. Rear wheel Z force transducer

3. CALIBRATION OF THE TRANSDUCERS

All the force transducers have been calibrated using dead weights to generate the forces (see fig. 8 and 9). The weights have been previously controlled, to an accuracy > 0.1%. The strain gage bridges have been supplied with 5V CC.

3.1. Calibration of the handles

The handle transducers have been calibrated up to their nominal forces: X – 100 N, Y and Z – 200 N. For all the transducers the linearity error is less than 1%.. The output signals of the 3 transducers of the handle (L_i) are related to the 3 forces acting on it (F_i) through the G matrix:

$$\{L\} = [G] \cdot \{F\} \qquad [K] = [G]^{-1}$$

$$\begin{Bmatrix} L_X \\ L_Y \\ L_Z \end{Bmatrix} = \begin{bmatrix} G_{XX} & G_{XY} & G_{XZ} \\ G_{YX} & G_{YY} & G_{YZ} \\ G_{ZX} & G_{ZY} & G_{ZZ} \end{bmatrix} \times \begin{Bmatrix} F_X \\ F_Y \\ F_Z \end{Bmatrix} \qquad \begin{Bmatrix} F_X \\ F_Y \\ F_Z \end{Bmatrix} = \begin{bmatrix} K_{XX} & K_{XY} & K_{XZ} \\ K_{YX} & K_{YY} & K_{YZ} \\ K_{ZX} & K_{ZY} & K_{ZZ} \end{bmatrix} \times \begin{Bmatrix} L_X \\ L_Y \\ L_Z \end{Bmatrix}$$

The components of the G matrix are obtained experimentally, by the calibration of the transducers. Then inverting the G matrix, the K matrix is obtained, that allows to calculate the 3 force components (F_i) from the 3 signals of the transducers (L_i).

Ideally the K matrix should be diagonal, so that each transducer is totally insensible to crossed forces. In the handle force transducer of the Walker the K matrix is nearly diagonal, but still has an out of diagonal member. This means that some calculations have to be done by the on-board computer to completely separate the 3 force components.

$$\begin{Bmatrix} F_X \\ F_Y \\ F_Z \end{Bmatrix} = \begin{bmatrix} K_{XX} & 0 & 0 \\ 0 & K_{YY} & 0 \\ 0 & 0 & K_{ZZ} \end{bmatrix} \times \begin{Bmatrix} L_X \\ L_Y \\ L_Z \end{Bmatrix} \qquad \begin{Bmatrix} F_X \\ F_Y \\ F_Z \end{Bmatrix} = \begin{bmatrix} 49{,}371 & 0 & -89{,}830 \\ 0 & 290{,}452 & 0 \\ 0 & 0 & 286{,}006 \end{bmatrix} \times \begin{Bmatrix} L_X \\ L_Y \\ L_Z \end{Bmatrix}$$

$$(N) \qquad \left(\frac{N}{mV/V}\right) \qquad (mV/V)$$

3.2. Calibration of the wheel transducers

The wheel transducers have been calibrated mounted in the walker (see fig 9), up to their nominal force: 200 N. The linearity error is less than 0.6%.

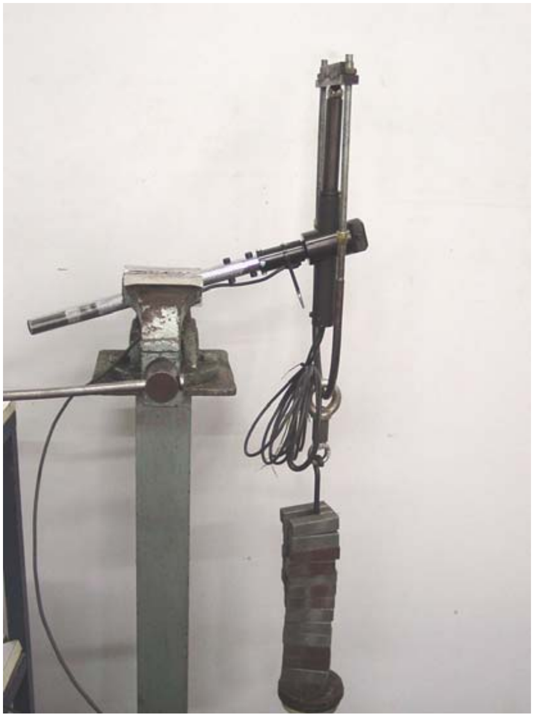


Figure 8. Calibration of the X force transducers

Figure 9. Calibration of the wheel transducers

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5. REFERENCES

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