FACTORS INFLUENCING THE HAND-ARM MECHANICAL IMPEDANCE

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1. INTRODUCTION

Several studies have focused on identification of the hand-arm driving point mechanical impedance (DPMI), pointing out how this quantity depends on the operator built, posture, grip and push forces, stimulus level and spectral content (Gurram et al. 1995; Gasparetto et al. 2004; Aldien et al. 2005; Marcotte et al. 2005; Aldien et al. 2006). The DPMI is commonly measured with instrumented handles, imposing a known vibration to the human limb and measuring the resulting forces. The measuring process is well consolidated, although errors may arise at high frequencies (Adewusi et al. 2008) because of handle dynamics. We describe here an experimental campaign whose aim is the evaluation of the factors affecting the DPMI at different frequencies, using the ANOVA technique. The first part describes the optimization of the method for DPMI measurements. The factorial design of experiments (DOE) was used to identify how the posture (elbow, shoulder and wrist angles), the grip and the push forces and the vibration level affect the DPMI at different frequencies.

2. METHOD

2.1. DPMI Measurement Set-up

An aluminum alloy handle was designed with finite elements methods so as to have a natural frequency above 3000 Hz. Two triaxial load cells PCB 260A11were used to measure the forces transmitted to the human limb. The acceleration generated by an electrodynamic shaker was measured with piezoelectric Bruel & Kjaer 4508B accelerometers. An image of the handle is shown in Figure 1. The vibration was imposed in a vertical direction; the handle axis has always been horizontal.

Figure 1. Instrumented handle for the hand-arm DPMI measurement.

The resonant frequency decrease due to the hand mass led to a systematic error (up to 10 %) not compensated by the handle idle mass subtraction. A correction procedure has been therefore developed creating a compensation function that accounts for the larger amplification when the resonant frequency decreases. The procedure can be summarized as follows - computation of the raw apparent mass, idle mass subtraction, and numerical (parabolic) compensation starting from the apparent mass at 1000 Hz.

With such a method, the apparent mass uncertainty in the frequency range 10 Hz – 1 kHz was lower than 5 % for masses ranging from 10 to 80 g. The DPMI has been eventually obtained multiplying the apparent mass by $j\omega$.

2.2. Posture Evaluation

Several bibliographical studies are based on subjective posture measurements; in this study six angles describing the upper limb configuration were measured with a vision-based system.

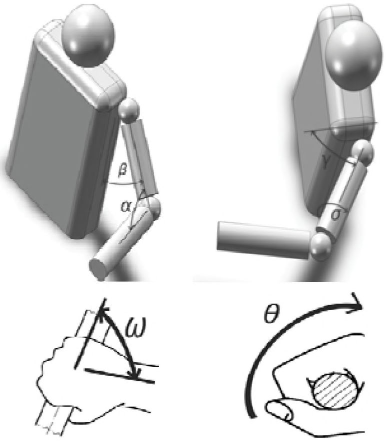


Figure 2. Six angles used to describe the upper limb posture.

Angles were measured starting from the position of adhesive markers attached to the testers' skin. The marker position was then identified with a pattern matching algorithm. Uncertainty of the measurement system was lower than 5°.

2.3. Force Measurements

The push force was evaluated with a dynamometric platform capable of measuring forces in the horizontal and vertical plane. The grip force has been measured before the tests with a pressure matrix manufactured by Novel GMBH. Testers were initially trained to produce a certain grip force and were required to reproduce such a condition during the shaker tests. Uncertainty deriving from this measurement method was quantified with purposely designed tests and was lower than 15 %.

2.4. Factorial DOE

A reduced factorial DOE was adopted; the nine factors included in the study were the six angles of Figure 2, the push and grip forces and the vibration amplitude. Factors levels were:

- α 0→180° 1→90°
- β 0→0° 1→90°
- γ 0→90° 1→60°
- σ 0→0° 1→30°
- θ 0→0° 1→30°
- ω 0→90° 1→60°
- feed 0→0 N 1→70 N
- grip 0→50 N 1→170 N
- F 0→4.5m/s^2 1→9m/s^2

F is the w_h-weighted stimulus level. The reduced factorial design included 16 tests - 7 male subjects (age between 25 and 30 years, heights between 1.70 and 1.90 m, mass between 70 and 95 kg) performed the 16 tests on 4 different days. The response variables were the DPMI evaluated in third of octaves bands at the center frequencies of 16, 31.5, 63, 125, 250 and 500 Hz.

3. RESULTS

A first analysis was performed to identify the posture variability during the tests. The α and β angles standard deviations were between 7 and 15 ° depending on the arm configuration. The σ angle standard deviation was 11°.

Analyses were then performed to identify how the DPMI is influenced by the investigated factors. The DPMI boxplots in third of octave bands is shown in Figure 3. Tests include impedances measured along the Z_h and X_h directions (the vibration was always vertical but the forearm could be horizontal or vertical). Data presented here therefore have to be compared with the weighted average of the Z_h and X_h ISO 10068 curves.

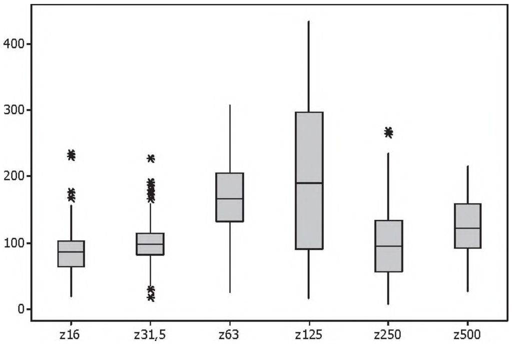
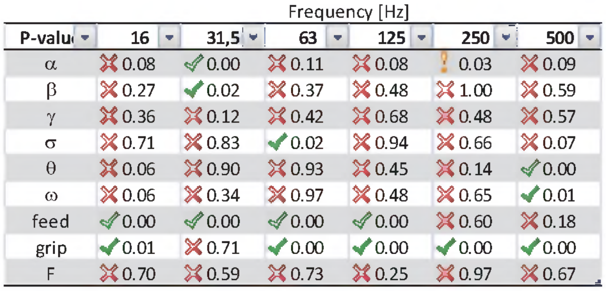


Figure 3. Boxplots of the DPMI (vertical axis) as a function of the frequency (horizontal axis)

ANOVA results are shown in Table 1. A factor influences the DPMI if the P-value is smaller than the type 1 risk (threshold in our case was set to 2 %).

Table 1. P values of the ANOVA tests. X non influencing factors, v influencing factors. ! a possibly influencing factor.



	Frequency [Hz]					
P-valu	16	31,5	63	125	250	500
α	✗ 0.08	✓ 0.00	✗ 0.11	✗ 0.08	! 0.03	✗ 0.09
β	✗ 0.27	✓ 0.02	✗ 0.37	✗ 0.48	✗ 1.00	✗ 0.59
γ	✗ 0.36	✗ 0.12	✗ 0.42	✗ 0.68	✗ 0.48	✗ 0.57
σ	✗ 0.71	✗ 0.83	✓ 0.02	✗ 0.94	✗ 0.66	✗ 0.07
θ	✗ 0.06	✗ 0.90	✗ 0.93	✗ 0.45	✗ 0.14	✓ 0.00
ω	✗ 0.06	✗ 0.34	✗ 0.97	✗ 0.48	✗ 0.65	✓ 0.01
feed	✓ 0.00	✓ 0.00	✓ 0.00	✓ 0.00	✗ 0.60	✗ 0.18
grip	✓ 0.01	✗ 0.71	✓ 0.00	✓ 0.00	✓ 0.00	✓ 0.00
F	✗ 0.70	✗ 0.59	✗ 0.73	✗ 0.25	✗ 0.97	✗ 0.67

4. DISCUSSION

In the investigated conditions, the DPMI depends from the grip force (all the bands but the 31.5 Hz one) and from the feed force (up to 125 Hz). A combined effect between these factors pointed out that the DPMI increases if one of these two factors is high; if both are simultaneously high the DPMI does not increase proportionally. The posture was important both at low frequencies (where DPMI is affected by the elbow and shoulder angles) and at high frequencies (where the wrist angles are important). The effect of the vibration level is limited; this leads to the conclusion that the adoption of a linear model is adequate.

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