Forces Applied on Rowing Ergometer Concept2®: a Kinetic Approach for Development (P94)

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Topics: Sport materials.

Abstract: Conception of rowing ergometer is constrained by many limits. One of them is that it must resist to forces applied on it, whatever is the frequency movement, and take few spaces in an apartment or a room. A good sport material must respect these two major constraints. In this study, we focus on resistance of material using forces quantification on each contact point on the rowing ergometer concept2® at different frequencies of practice. Our goal is to reveal where structure modifications could be effected in order to optimize conception. There are four contact points on this ergometer: "the handle, the seat and the two foot-stretchers". On each point, forces are measured with a specific material. On the handle, a mono-directional sensor is used. Under the seat and the two foot-stretchers, 6 axis force plates were used. These measurements are realised with an expert rower who practice rowing on the concept2® ergometer more than twice in a week and is an international level rower on boat. One rowing cycle is selected for each produced stroke rate: 18 to 40 strokes per minute. First results show that forces are not really modified when stroke rate increases. Secondly, forces produced under the seat are not constant. An inertial parameter explains this inconstancy: the accelerated rower masses of his trunk and his upper limbs. Finally, on stretcher, forces are different too because of inertial effect of whole body at the end of recovery. In resume, the structure of concept2® ergometer can be optimised, changed and probably costs less if we take into account this type measurements before design a rowing ergometer.

Keywords: Rowing ergometer, applied forces, kinetics and performance.

1- Introduction

The design of sport ergometers requires thorough knowledge of the studied sport. The design is characterized by the dilemma space and weight equipment versus resistance to the activity. Mechanically, it has to resist to the efforts developed by costumers. This resistance has to be sustainable over time. Moreover, the finished structure must allow a

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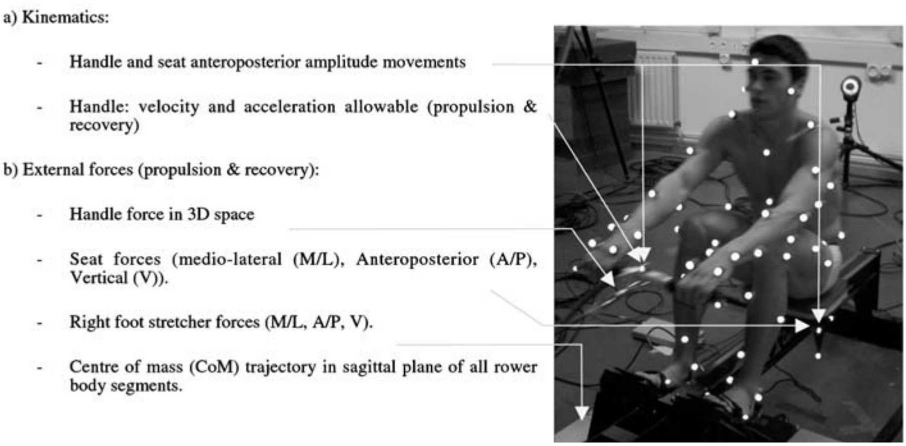
practice in all of the practicing movement amplitude [1], and must take a minimum living space too. Moreover, the weight of the finished structure becomes predominant when the population becomes more and more old [2]. In this paper, the studied activity is rowing. It imposes several constraints to manufacturers because it is a sport that can be done with a development of small forces (elders) to very high (expert rowers) at each contact point between costumer and ergometer. At the moment, some rowing ergometers coexist and each have their specificities, but to optimize the structure of the ergometer, engineers need to know precisely which constraints the whole structure will have to withstand. Currently in the literature few data are clearly described. Pudlo *et al.* [3] have instrumented a Concept2 rowing ergometer ® Type C and have tested it with a French regional level rower. Nevertheless, these data are not significant enough in order to characterize atypical or extreme practice. The purpose of this paper is to provide all the kinetic or kinematic data needed to design a rowing ergometer considering an extreme use. The presented data will come from a movement realised by a very high level rower at different stroke rates: training and racing. This study is based on the same existing ergometer as Pudlo *et al.* [3] but the expert rower is a French champion and member of the French team.

2- Protocol and Method

2.1 Protocol

To define rowing ergometer characteristics, conception teams must have a review of kinematics and kinetics data of extreme rowing activity. Consequently, the followed data are measured or calculated with respect of experimental instructions.

2.1.1 Measured and calculated data



2.1.2 Experiments

A French rower gold medallist at French championship in double scull lightweight is tested on the instrumented ergometer. His characteristics are: 28 y.o., weight: 72.5 kg, height: 1.73 m. The experiments consist to row on Concept2® ergometer at stroke rates between18 to 40(strokes.min^{-1}). One cycle for each stroke rate is recorded.

2.2 Experimental Apparatus

The experimental apparatus comprised a 3D motion analysis system, a Concept2® ergometer Type C (Morrisville, VT, USA), 3 six-axis force-plates, and 1 mono-dimensional force transducer (Figure 1).

2.1.1 The motion capture system

The motion capture system VICON 612 (Oxford Metrics, Oxford, UK) is composed by 8 cameras placed around the ergometer and coupled with an analogue acquisition of the force transducers. The kinematics and kinetics data acquisition frequency is 60Hz. The reference frame is defined by the M/L axis (pointing to the right), A/P axis (pointing forwards) and V axis (pointing upward).

2.1.2 Stretchers Instrumentation

Two three-axis forceplates (PX2000, LOGABEX, Giat-Industrie) are placed under two stretchers independent of the ergometer. The force measurement range is 5500 N for M/L and A/P components, 21000 N for the V component. These forceplates are considered to be sufficient since they allow recordings at levels higher than the force peak recorded by MacFarlane *et al.* (1997) which was equal to 900 N.

2.1.3 Seat instrumentation

A third three-axis miniature forceplate (EX114.45-200, LOGABEX, Giat-Industrie) is fixed under the ergometer seat. Its measurement range is 2000 N for the V component, 500 N for the M/L and A/P components. The error given by the manufacturer on each component is 1% of the measurement range.

2.1.4 Handle instrumentation

One mono-dimensional force transducers (ELHM-T3M-10KN, ENTRAN), with a measurement range of 10000 N, allowable overcharge of 5000 N and error is less than 0.01%, operates in traction-compression mode. This transducer was considered sufficient since tests performed on 81 national level heavy-weight rowers showed that cumulated force from both hands was maximal at the start of the race, reaching 1352 +/-109 N (Hartmann *et al.*, 1993). This transducer allows dynamic and static forces measurements. This transducer is located at handle / chain interface. The 3 components of F are calculated in the global reference frame.

3- Results

The results are exposed in relation with the design procedures and as a function of stroke rate.

3.1 Kinematics

3.1.1 Handle and seat displacements

To determine seat rail and chain length needed for this rower practice, seat and handle movements have been measured and results are expressed in table 1.

Table 1 - Seat and handle amplitudes with stroke rate increase.

	Stroke rates						
Amplitudes	18	20	24	28	32	36	40
Seat	**531**	521	513	498	515	493	508
Handle A/P	1453	1467	**1480**	1447	1453	1437	1400
Handle V	185	181	175	179	180	195	**215**

This table shows that the biggest amplitude displacement of the seat is obtained at 18 strokes.min^{-1} with 531mm. It shows too that the biggest anteroposterior amplitude (1480mm) and vertical amplitude (215mm) are respectively obtained at 28 and 40 strokes.min^{-1} (see also, Figure 6). Consequently, a maximal seat rail and chain lengths is not necessary obtained with an extreme practice and confirm that stroke rate is not a necessary factor to take into account for these lengths.

3.1.2 Handle velocity and acceleration on each rowing phase

To give maximal values of handle when the stroke rate increases, figure has to be analysed. The figure 1 (a) shows the handle velocity during propulsive phase. At 40 stroke.min^{-1}, the handle velocity is at its maximum with 2.4m.s^{-1}. More the costumer increases the stroke, more the handle velocity increases. Then, it is necessary to have a handle which can move at this velocity without adding passive friction. Indeed, the customers adjust the air-braked flywheel to limit the lumbar injury that can be induced by regular and intense practice. The injury mechanism can be explained by the Figure 1 (b). The acceleration is intense on start of propulsive phase and grows up to “0” at 18-20% of the propulsive phase. When the acceleration is around 0 the force applied to the handle is maximal. At this moment, the joint moment applied at the level of L5 is maximal because the posture of the rower induced a maximal lever arm. On recovery phase, handle velocity and acceleration is quasi symmetrical to the propulsive phase. Likewise during the recovery phase, the passive friction of the handle has to be minimised because it does not penalise the chain coming in. During this phase, the flywheel does not produce; of course, any reaction force, nevertheless the recovery phase is important and can’t be ignored because it’s a rest time during the effort.

Kinematics data leads to determine the ergometer geometry. Kinetics data provides more information about the constraints exerted on the ergometer.

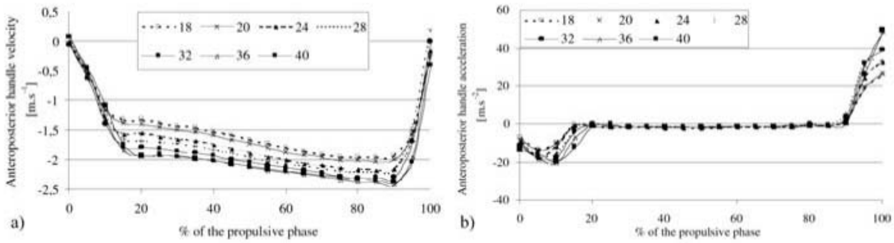


Figure 1 - Handle velocity (a) and acceleration (b) during propulsive phase at different stroke rates.

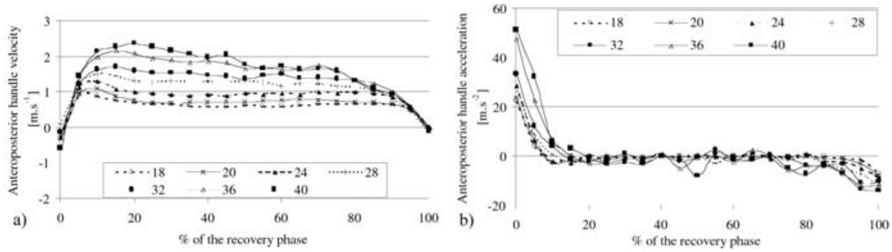


Figure 2 - Handle velocity (a) and acceleration (b) during recovery phase at different stroke rates.

3.2 External forces

3.2.1 Handle force

Maximal handle force developed by the tested rower is around 1050 N (figure 3, a). This maximal value of handle force during propulsion is constant what the maintained stroke rate is. The figure 3 (b) shows that force developed at the handle by the rower during the recovery stays positive and quasi constant at 20N whatever the stoke rate. The fact that the handle force stays positive could be explained by the coming in of the chain by elastic. The recovery phase using an ergometer is different than the practice of rowing on boat [4, 5, 6]. The engineer can use this gap on the actual ergometer to propose technological solution to optimise the simulation of boat rowing on ergometer.

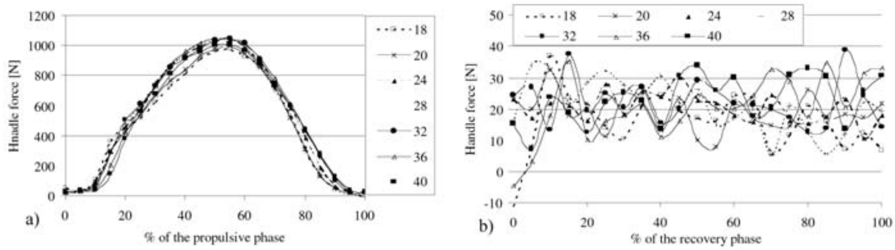


Figure 3 - Force measured at the chain / handle interface during propulsion (a) and recovery (b) rowing phase.

3.2.2 Seat forces

The seat ergometer has been a revolution in rowing sport because it permits rowers to increase the distance of their blade on water activity. That's why, on ergometer, seat is an important parameter because it permits rowers to have a greatest handle amplitude without any fright of disequilibrium. So the seat must have to support the weight of the rower but not only. The figure 4 represents forces at stroke rate 18 and 40.

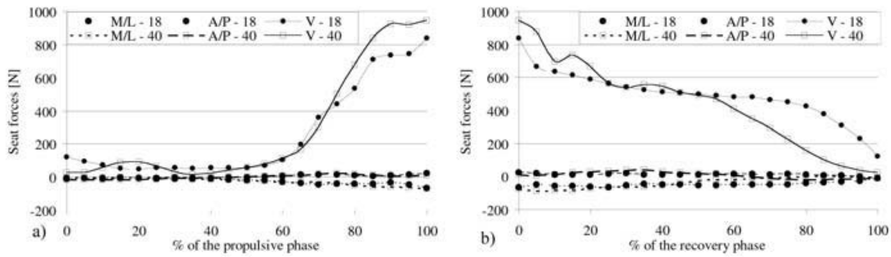


Figure 4 - Force measured under the seat during propulsion (a) and recovery (b) rowing phase.

This figure shows a lightening of the rower during the first middle part of propulsive phase. Effectively, he pushes on his legs (Figure 4, a) backward and downward. But at the end of propulsive phase, the vertical forces measured grow up until 711 N (the weight of the rower). The same observation can be done at the beginning of the recovery phase (Figure 4, b). During the first 60% of the recovery phase, a vertical force is measured by the instrumented seat. It seems to have no compensation on this part of movement. Finally, on the other axis, there is no important force applied. Consequently, this observation can be used to propose a seat lightening in order to win weight on the ergometer.

3.2.3 Foot stretcher forces

Foot stretchers have to support the pushing force produced by legs during propulsive phase but not also, they must be able to accept the pulling forces developed during inversion movement of rower during recovery phase.

On propulsive phase, figure 5 (a) shows that on the first 50% of this phase, A/P force increases up to 500N and V force stay nearly constant at 300N. A/P force is the most comprehensive force applied on stretchers because the rower pushes on them. Such as V force is constant during those 50% we can suppose that the rower is "standing up" on the foot stretchers. Then, this result can explain the fact that on the seat, there is less weight measured than the body mass value. The end of propulsion is characterised by negative A/P and V forces. This data shows that rower realised a pulling phase on stretcher to compensate the trunk inclination at this moment.

On recovery phase, V and A/P forces grow up during all the recovery phase. Indeed, the rower places his body segments near foot stretcher.

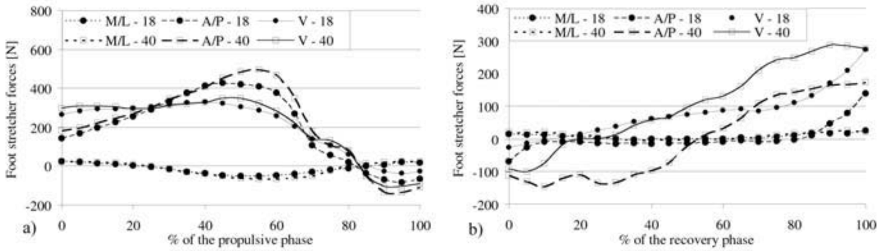


Figure 5 - Force measured under the right foot stretcher during propulsion (a) and recovery (b) rowing phase.

3.2.4 CoM positions during cycle

Rower CoM during the whole cycle can give information about the multi-compensation of forces realised by the rower measured on ergometer. On figure 6, CoM altitude decreases about 80mm at the end of propulsion. This decreasing informs on the reaction force measured at the seat because trunk acceleration influence forces on the seat. This information is confirmed by upper results. Displacement of CoM during cycle is unchanged with stroke rate and so the coverage zone of CoM displacement on the rail is always the same for this rower. So, it can be determined where the rail must be the most robust.

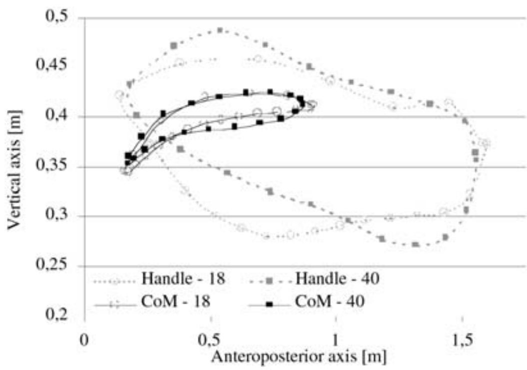


Figure 6 - Rower CoM on a rowing ergometer cycle : recovery is represented by the lower part and propulsion by the upper part of curves.

4- Discussion

Our results provide information needed by designers on handle, seat and structure when a high level rower uses them at different stroke rates. Handle and seat displacements leads to determine the geometry of the ergometer. Handle velocity and acceleration provide to designers characteristics of chain come in and in comparison with the real activity of on-water rowing. We can note that there is no attractive force on the row handle while on this ergometer there is one during recovery where the rower are not pulling the handle but pushing it. It informs designers who continue to consider the centred pulling handle as the best solution while it does not represent the real practice of on-water rowing. External forces measured at each contact point shows that kinetics of rowing movement is not so easy. The handle pulling force analysis shows that it does not change with stroke rate level but its maximum is near the 1050N and so components must resist at this pulling force. The seat pressure analysis shows that the seat must support heavy charge especially at the end of propulsive phase when trunk is on back. Stretcher analysis shows that rower produces a leg pushing during the first 50% of propulsive phase and just after he adjusts his body segment posture in order to stop his body segment inertia. On recovery phase, the rower just returns on the catch position in order to engage a new cycle. Finally, CoM displacement of the rower shows that he uses his trunk as an accelerated inert mass in order to increase handle velocity until the 90% of propulsive phase that confirm past results on ergometer or on boat [5]. Designers must take into account this information to develop an intelligent seat which permits a better shock absorption at the end of propulsion. This study concerns one lightweight high level rower and so can not be sufficient for an efficient ergometer conception but gives a good starting database in order to design a new rowing ergometer on which tests will be reprocessed.

5- References

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