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"THE 6 - MINUTES WALK TEST ON THE TREADMILL CONTROLLED BY A PATIENT'S WALK"

The paper describes reasons and a series of works which have led to development of new type treadmill adapted to realize the 6 – minutes walk test. The new treadmill which allows the patient to walk with their own pace could be useful in rehabilitation, evaluation of physical efficiency, sport trainings and recreation.

1. INTRODUCTION

The American Thoracic Society (ATS) in 2002 definitely recognize the six-minutes walk test (6MWT) as a useful tool for the evaluation of physical efficiency in individuals with at least moderate chronic obstructive pulmonary disease, heart failure and intermittent dysbasia [1]. In order to compare the results obtained in various research centers, the hallway 30 m in length and at least 3 m in width is recommended. Unfortunately, many centers without such hallways have a limited possibility of carrying out the comparative test.

The authors of the ATS report appreciate the advantages of the 6MWT on a treadmill as it saves space and allows constant monitoring during the exercise. However, ATS has not approved the use of a treadmill to determine the six-minute walking distance (6MWD) because, so far, patients are unable to pace themselves on an ordinary treadmill.

The divergence between the distance covered on the treadmill and in the hallway was pointed out. To support this point of view, a study of patients with severe lung disease was presented, where the mean distance walked on the treadmill was shorter than 14%, when compared with the standard 6MWD using a 100-ft hallway [2]. In particular, doubts were expressed regarding the wide range of differences, for patients walking between 400-1,300 ft on the treadmill and 1,200 ft in the hallway.

The popularity of the 6MWT in clinical practice [3, 4, 5, 6], problems with the performance of the test on the treadmill, as well as the differences between the 6MWT in the hallway and on the treadmill encouraged us to develop a treadmill, which applies the algorithm of the safe speed adjustment to the walking capacity of the patient. The purpose of our work was to construct treadmill, which lets patients to move with their own pace during the walk and checks that such treadmill will be sufficient to realize 6MWT.

2. PRELIMINARY WORKS

The common treadmill forced patients to adjust theirs walking speed to its belt speed, otherwise, they will be thrown away outside the belt. The new treadmill ought to change its belt speed, when patient's walk speed changes and make it quick enough, to keep patient still on the treadmill. In the beginning, the preparation of such a treadmill seemed us difficult and other solution has been chosen. We decided to combine speed of the belt with the patient position on the surface of the treadmill. When patient is close to the front of the treadmill, the maximum speed of the belt is achieved, when he is close to the end of treadmill the belt stops. Increasing the walking speed the patient moves toward the front of treadmill and the belt speed increases, when he slows, belt moves him backward and the speed of the belt is adjusting again. In order to realize such algorithm, precise measurements of patient position on treadmill are necessary. Already in the beginning, due to inconvenience of other methods, decision has been made to measure position wirelessly.

First of all, use of ultrasound wave, reflected by patient on treadmill has been chosen to measure distance from the patient to the front of treadmill. Due to parasitical echoes from the other objects around, measurements were uncertain and the method turned out to be inconvenient. Because transmitting and receiving of ultrasonic wave is simply and cheap in realization, we decided to continue using ultrasound after little modification. In new method patient was carrying transmitter, which produced simultaneously short impulse of ultrasound wave and infrared beam (about 100 milliseconds long). Both signals were received by receiver at front of treadmill and distance between transmitter and receiver has been calculated from time delay between received signals. Distance measurements turned out to be accurate (error less than 10 mm) and due to shortest direct way of ultrasound signal parasitical echoes did not disturb measurements. Fig.1 shows idea of the patient's position measurement using mixed ultrasound/infrared method. Carrying of transmitter seemed slightly uncomfortable for patient, but safe, because only person carrying transmitter could operate the treadmill. Additionally, infrared beam would be used to transmit patient heart rate (HR) to display at the front of treadmill.
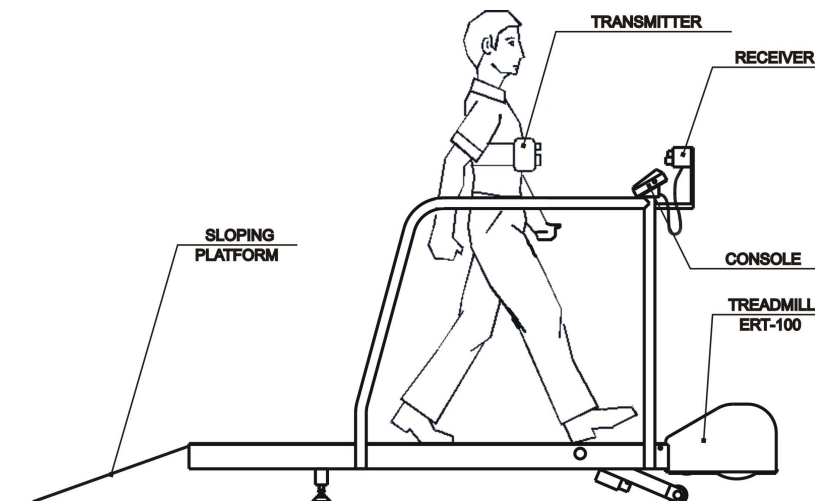

Fig.1 6 - minutes walk test on treadmill

When position measurement system with transmitter and receiver was ready, preparation of the treadmill to speed controlling has begun. We adapted produced by ITAM

treadmill ERT-100, connecting receiver and introducing new control program to its console. Using " the 6 – minutes walk test program" in control panel, operator could input maximum speed of the treadmill belt and start the test. After 6 minutes from start of test program terminated test and displayed the distance covered by patient. The treadmill belt achieved its maximum speed when distance between receiver and transmitter was less than 30 centimeters and stopped when distance had been exceeded 120 centimeters. Between those two distances speed was changing proportionally from 0 to maximal value which could not exceed 10 kilometers per hour.

The ERM-100 treadmill, modified as described above, has been examined by a group of 29 healthy volunteers which performed both 6MWT on the treadmill and in the corridor in 7 day interval, as described in [7]. Distances covered by volunteers in both tests were similar and participants had founded treadmill test more comfortable than corridor test. Although the results were satisfying some drawbacks of treadmill and control algorithm appeared:

- the treadmill ERT-100 was too short for such control algorithm an additional sloping platform became necessary for patient safety, rapid stop of the patient could be dangerous for him
- range of position change was narrow which cased restless speed of the belt, slight changes caused perceptible change of speed
- belt speed change ramp was to slow and treadmill react to slow for rapid changes of patient speed
- illusion of similarity to walk in corridor was partial, patient always had to keep attention only to preserve desired speed

It was obvious that we could not change the treadmill to eliminate all of this disadvantages, so we had to prepare new control algorithm instead.

3. MAIN RESULTS

New idea of treadmill control shows Fig.2 Block diagram. The way of distance measuring has been left the same but receiver has got additional functions.
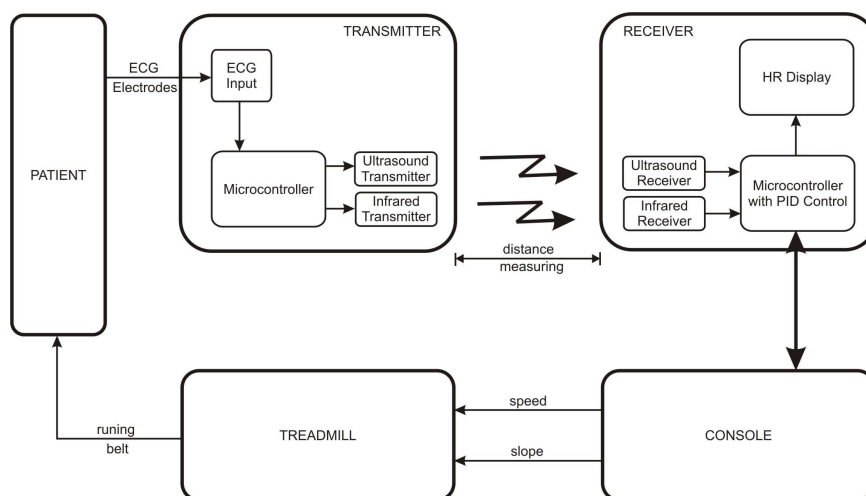

Fig.2 Block diagram of treadmill control by the patient walk

Opposite to former version, console is used only for communication with operator. The treadmill control algorithm is realized by microcontroller in the receiver where console only transfers speed and slope signal to treadmill.

The belt speed change ramp which was programmed in console has now been changing according to requirements of performed test. We decided to return to idea of the treadmill which change its belt speed when patient walk speed changes and make it quick enough to keep patient constant position on the treadmill. The microcontroler in receiver maintains patient constant position on the treadmill independently from walk speed using controller utilizing PID algorithm (proportional – integral – derivative). Algorithm takes into consideration maximum allowed belt speed set in console by operator and maximum allowed distance from receiver in which belt stops. This distance lets patient stops without risk of throw away outside of the treadmill. Fig. 3 shows block diagram of PID control algorithm.
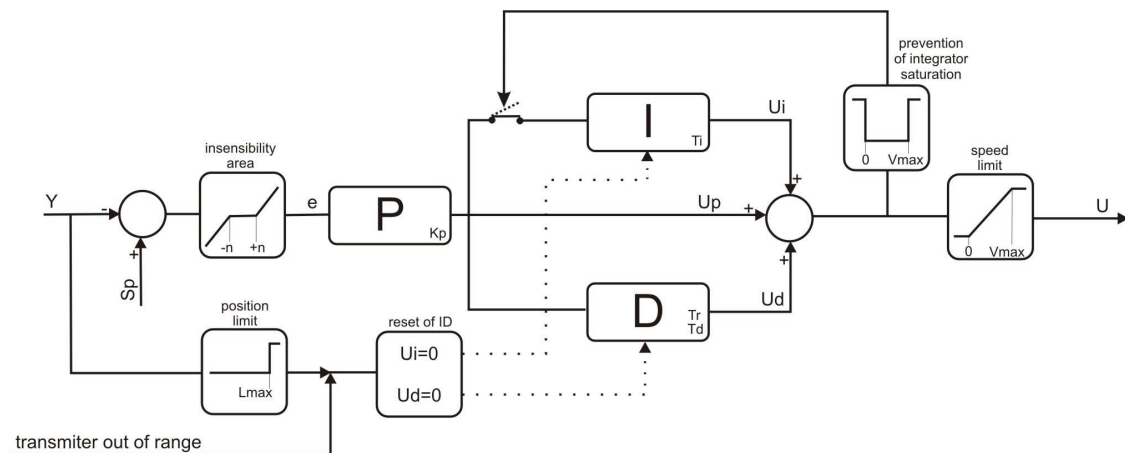

Fig.3 PID controller algorithm

In above diagram symbol means:

Y - the distance between transmitter and receiver
S$_p$ - the preset patient position on the treadmill
U - the treadmill belt speed
e - error, difference between preset position and current distance

K$_p$ - the controller proportional gain
T$_I$ - the controller integral time
T$_r$ - the controller derivative time
T$_d$ - the inertia time base

Equations which describe each part of PID controller:

P: $Up(s) = k_p \cdot e(s)$

D: $Ud(s) = k_p \cdot \dfrac{s \cdot T_r}{1 + s \cdot T_d} \cdot e(s)$

I: $Ui(s) = k_p \cdot \dfrac{1}{s \cdot T_i} \cdot e(s)$

U: $U(s) = Up(s) + Ui(s) + Ud(s)$

Several additional blocks have been added to standard PID controller structure. First, the insensibility area block prevents PID operating when difference between patient position and preset position is negligible. Second, speed limit block prevents patient from belt speeds which could be dangerous. Limit is preset by treadmill operator. Third, the position limit block stops treadmill belt when patient position is outside controlling range. The same effect is caused by lost of transmitter signals e.g. when transmitter is out of range or inoperative. Another block which prevents integrator from saturation, stops integration when belt speed is out of range. Last block resets controller integral and derivative blocks.

The treadmill control using PID controller described above has been simulated with the use of LabView programme. Simulation lets us specify rough parameters of controller. Fig. 4 shows LabView screen during the treadmill belt speed controlling simulation. Programme of PID controller was implemented, with constants specified during simulation, into receiver's microcontroller and checked by volunteers, which have been walking on treadmill with different speeds. During testing, PID controller parameter has been tuning to achieve the best results.
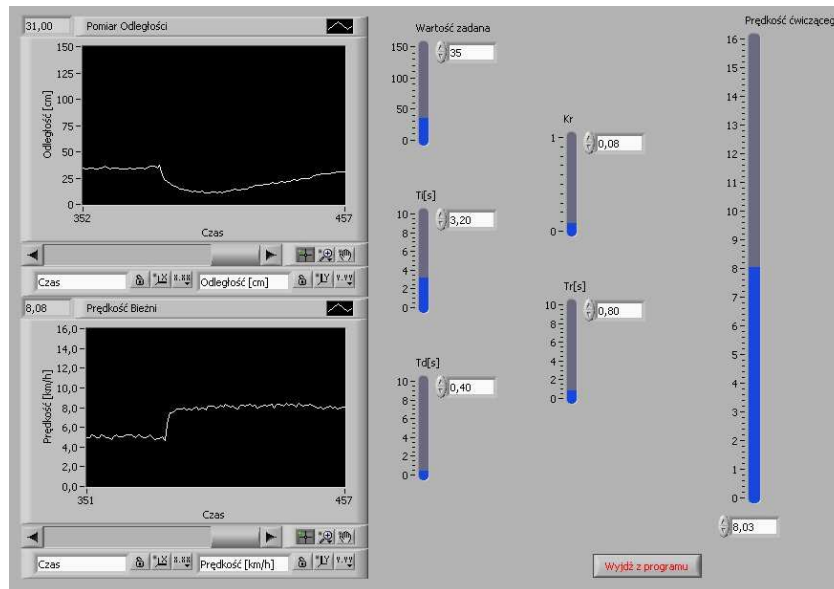

Fig. 4 LabView simulation

Testing personnel had often different subjective meaning about the best sets of controller constant. Each person had his own favorite algorithm. The difference seemed to be negligible but will became greater when greater difference among patients will occur (due to age, incapacity, disability).

At the end of tests additional test has been made which utilized the treadmill ability of elevation changing. During the 6MWT after covering part of way preset in program, treadmill changed elevation to value specified in program. Test showed that elevation changes did not affect test execution.

4. CONCLUSIONS

As the results we achieved the algorithm which made 6 minutes walk test on the treadmill much more safety than in the beginning and very similar to classical corridor test. It allowed us to prepare commercial version of ERT-100 treadmill equipped with transmitter and receiver and finally carried out CE certification procedure.

Probably the treadmills should be equipped with several algorithms, each focused on different group of persons (elderly or young, fit or incapable). The treadmill with CE certificate allows to choose the best control algorithm for each group of people by research carried out on large population.

The "6 minutes walk test" is not the only application of the treadmill controlled by the patient's walk. It is easy to imagine many other tests which use the same principle. For

example "2 – kilometers walk test" where principle of 6MWT is inverted, time elapsed after covering distance is the final result. Adding to walk elevation changes of the treadmill we get system which simulates cross country test, unknown in medicine but well known in sport trainings.

ITAM prepares the new family of treadmill with new features and enhanced abilities (e.g. enhanced dimensions, higher speed). The new treadmills will be equipped with algorithm which controls belt speed not only by walk of the patient but even while the patient is running.

Position measuring is essential of treadmill controlling by patient walk. Works are carrying on with new family of treadmill to use other methods to determine position of the patient, and achieved results seem the same or even better than before.

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