7M.WT

N.B. Proper dwgs. are in work

8.a. Purpose - The improvements described will allow the effective, quantitative use of human treadmills in weightlessness to prevent loss of muscle, bone and cardiovascular capacity. It will also allow quantitative investigation into effects of exercise and physiological problems. The following measurements can be performed by these improvements:

1. Equivalent 1-g subject weight
2. Instantaneous major foot/ground force component
3. Total external work
4. Equivalent 1-g grade

These parameters are not currently available from treadmills in space but are essential to their rational use.

9.b. - Some biomechanics and physiology of treadmill locomotion and differences in such locomotion on Earth and in weightless environments must be understood before the advantages of the described system can be appreciated. In level 1-g locomotion there are varying force vectors during foot ground contact which may be resolved into vertical, and horizontal fore-aft, and lateral components. Figure 1 . In level, steady state locomotion mean external work is zero. Conversely, internal work done by the subject is a function of subject weight, locomotion mode (walk, run) and speed. On Earth this work is also a function of treadmill elevation or grade. Grade and speed are the two universally measured parameters since relative subject work level is the usual parameter of interest in 1-g studies.

In weightlessness, Figure 2A, equivalent body weight (F) and grade (θ) must be artificially provided. With passive (subject driven) T.M.'s (Figure 2B) some equivalent grade (θ) must be provided to overcome friction. Also in space flight, foot ground (tread) forces are of great significance in research and in effective use of exercise to prevent muscle/bone loss. None of the above parameters are currently available in US or USSR treadmills. The USSR space treadmill was first flown in 1970 and appears unchanged. It consists of elastic bungees and a harness to provide a partial equivalent of body weight apparently estimated by mechanical adjustments. The treadmill chassis is either passive or active (motor driven) but so far as can be determined no instrumentation for measuring speed or equivalent grade exists or has been described.

The US space treadmills, all designed by the author to date, have mechanical means for applying forces estimated equivalent to body weight, are passive and have speed indicators only.

c. Space treadmills to date lack measurement of several parameters, essential to their proper application including; accurate equivalent body weight, foot ground forces, and external work or equivalent 1-g elevation.

d. The disclosed treadmill will include, in addition to adjustable subject equivalent weight force load and belt velocity, the following measurements:

1. Mean subject vertical (F_z) foot/ground force (FGF) (equivalent to weight on Earth)
2. Instantaneous vertical (F_z) FGF
3. Mean fore-aft horizontal (F_x) FGF

4. Equivalent 1-g elevation

5. External work

This is accomplished as follows:

Forces normal to the tread are measured by an ensemble of strain gages, Figure 3, which are sensitive in only the vertical axis and are mounted as shown. In some cases more than four gages may be required. Such gages are well known and commercially available. Further, they are available in matched sets such that they can be used in parallel as in Figure 4A to provide total force. An alternative scheme for summation is shown in 4B. A variable offset current A or voltage B may be used to adjust for tare weight on Earth and to eliminate any zero drift (r_1r_2). Finally, the signal is averaged for use in the following system. Figure 4C. It is essential that the weight of the subject be freely transmitted to the carrier rollers, i.e., the belt must be flexible and that vertical forces are not generated by movement of the belt over the rollers, conditions which can be met. The first use made of the vertical force (F_z) is to display it on a conventional meter in terms of pounds equivalent body weight during "weight" adjustment and subject static. This will allow accurate adjustment of equivalent body weight with the subject load system, Figure 5. Next the signal may be stored or displayed such instantaneous FGF normal to the tread are registered for study. This is the major force generated in locomotion. Finally, the signal is averaged $\overline{E}_{fz}$ for use in the following system.

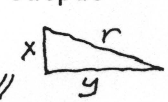
Horizontal, Fx, FGF is measured with a pair of strain gages sensitive only in the X-axis. The arrangement is shown as in Figure 6. With this arrangement, the desired force, Fx, may be obtained by subtracting output the gages Fx_1-Fx_2 to remove the static tension component. This may be done by direct connection of the gages as in Figure 7A or B or with summing amplifiers as C.

1. A number of other electro mechanical systems could be used to accomplish this but the gages appear to be the simplest. By adjusting scale factors, external work on the treadmill may be obtained by multiplying the mean Fx force by the treadmill speed signal as in Figure 7D. An analog tread speed voltage is produced on the U.S. treadmills by a tachometer which may be used.

Since most researchers are unfamiliar with treadmill work loads and use grade and speed as the measure of work (they are equivalent), grade may be obtained by dividing mean Fz by Fx, Figure 7E. *

e. A wide range of electromechanical arrangements to achieve the results are obviously possible. In additional there may be variations in location and number of force elements supplying body equivalent weight, for while the two element fore-aft scheme is planned for future U.S. use, all U.S. units to date have used four elastic elements as in Figure 8A and the USSR units use two lateral units as in 8B. So long as the horizontal gages are sensitive only in the single axis, X, they may be used as follows. Output

* There is an argument as to how grades are defined. ie. whether by $\frac{x}{y}$ or $\frac{r}{y}$ in case of the latter a ckt. will be added to obtain r from $r = \sqrt{x^2 + y^2}$ -



of the lateral mounted gages may be simply summed since only horizontal forces against the tread are sensed. In the case of four tension elements output of the two forward and two rear elements are summed to obtain total force and then the front force is subtracted from the rear as before.

The foregoing measurements are made on the assumption that the subject is not supported at any points other than the tread and by the load system. If he is supported elsewhere such as a handle then these forces must be added to the other forces derived. In the case the handle is used for support an additional pair of gages sensitive only in single axes, ΔFz + ΔFx, which measure forces in the handle and these may be added to signals as in Figure 9.

Although shown as analog processing, the signals may be digitized and manipulated by microprocessing through well known techniques.

It makes no difference if the treadmill is active or passive, to this system.

f. Previous treadmills have not provided data essential for their proper usage in weightlessness as either a countermeasure or for study. Since crew time is at a premium in flight, efficient utilization is critical. To be effective, certain critical limits must be achieved in force and work loads and this system provides such information for the first time, e.g., USSR cosmonauts are currently spending 2+ hours/day exercising on long flights and proper use of data provided here could sharply reduce this.

h. New features for treadmill use in space flight (weightlessness) include:

Ability to accurately adjust equivalent body weight through registration and display of static vertical forces.

Means to register the major instantaneous components of foot ground forces.

Measurement of mean horizontal foot ground forces.

Measurement of external power and work done on a treadmill in weightlessness

Derivation of equivalent 1-g grades.