Test Report

Tubetrainer

Commissioned by:

Cuckoo Company

Issued by:

The Hague University of Professional Education

Department of Human Kinetics

ECBY

Center of Expertise

In collaboration with:

Office of Motion Technology Concepts

Foreword

The tube trainer is essentially a tube containing a freely moving internal mass. The tube is easy to handle and allows for a large variety of patterns and positions of free, unrestricted movements. The freely moving mass in the tube ensures that an additional mechanical load is brought into play when the direction of the shifting mass is reversed.

In that the shifting mass moves inside the tube trainer, there is a resultant difference in impact, as do the uses of varying types of masses. In order to determine the respective effects of differing forms of contents, the Cuckoo Company has requested to examine the different contents in a tube trainer.

This project was conducted by the Center of Expertise of Motion Technology at the Hague University of Professional Education, in collaboration with the BOB (Office of Motion Technology Concepts) enterprise, in which the testing was concerned with the differing effects of tube trainers with varying contents.

This test report is intended for Cuckoo Company for clarification and support purposes as regards the function of the tube trainers. Additionally, those individuals who find this a subject of interest or who work in this field may refer to this report for its findings.

The Hague, August 2005

Center of Expertise of Motion Technology and Office of Motion Technology Concepts

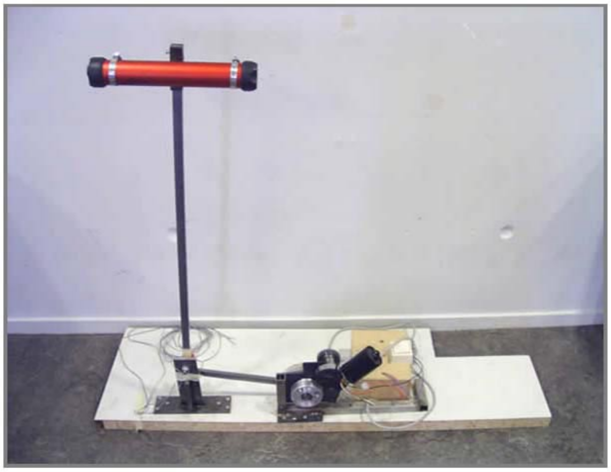
Abstract

1. Testing Protocols

1.1 Testing Equipment

The following equipment was required for conducting the tests:
- test assembly
- tube trainers
- strain gauges
- multimeter
- Active DAQ (Device for Data Acquisition)
- MATLAB

The adjoining photo shows the test assembly. This assembly consists of a motorized arm (length: .8 meters) which can swing back and forth. Above the lever's pivot point, a strain gauge is positioned vertically to the lever's longitudinal axis. The tube trainer can be fastened to the top of the arm's lever.

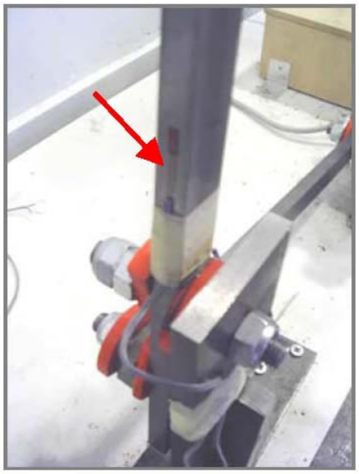


Six tubes of 1.25 liters and two of .63 liters, each with a different filling, were used for the tests, specifically as follows:

1. Original	1.25 liter tube with original slate granulate filling
2. Solid	1.25 liter tube, filled with a solid mass
3. Fine	1.25 liter tube, filled with fine slate granulate
4. Water	1.25 liter tube, filled with water
5. Marbles & Slate	1.25 liter tube, filled with marbles and slate granulate
6. Marbles	1.25 liter tube, filled with marbles
7. Original Small	0.63 liter tube with original slate granulate filling
8. Solid Small	0.63 liter tube, filled with a solid mass

The values obtained from the strain gauge are analyzed at the end of the study. A strain gauge is a sensor which measures small changes in lengths. It is little more than a wire with a given electrical resistance. When the wire changes its length, corresponding variances in resistance occur (a shortened wire results in decreased resistance, whereas a lengthened wire shows increased resistance). Within given limits, the relative changes in resistance are directly proportional to the elongations caused by the respective strains. By attaching the strain gauge directly to the distorting material, the attendant strain on the object can be measured.

/Right: photo with caption: /Illus. 1.2: strain gauge



The Active DAQ measures the resistance as captured by the strain gauge and sends the signal to the AD converter. This device converts an analog signal to a digital one, which can be read by MATLAB. MATLAB stands for Matrix Laboratory and is an interactive software package for numerical calculations.

To validate a result, the test assembly must be calibrated. This is done with a multimeter.

1.2 Measuring Protocols

Prior to starting any testing with the tube trainers, the test assembly must first be calibrated. By loading the arm with a 10N weight, the strain gauge begins to stretch. The ensuing value can be related to the force imparted by the tube trainer. The multimeter ensures the accuracy of this method.

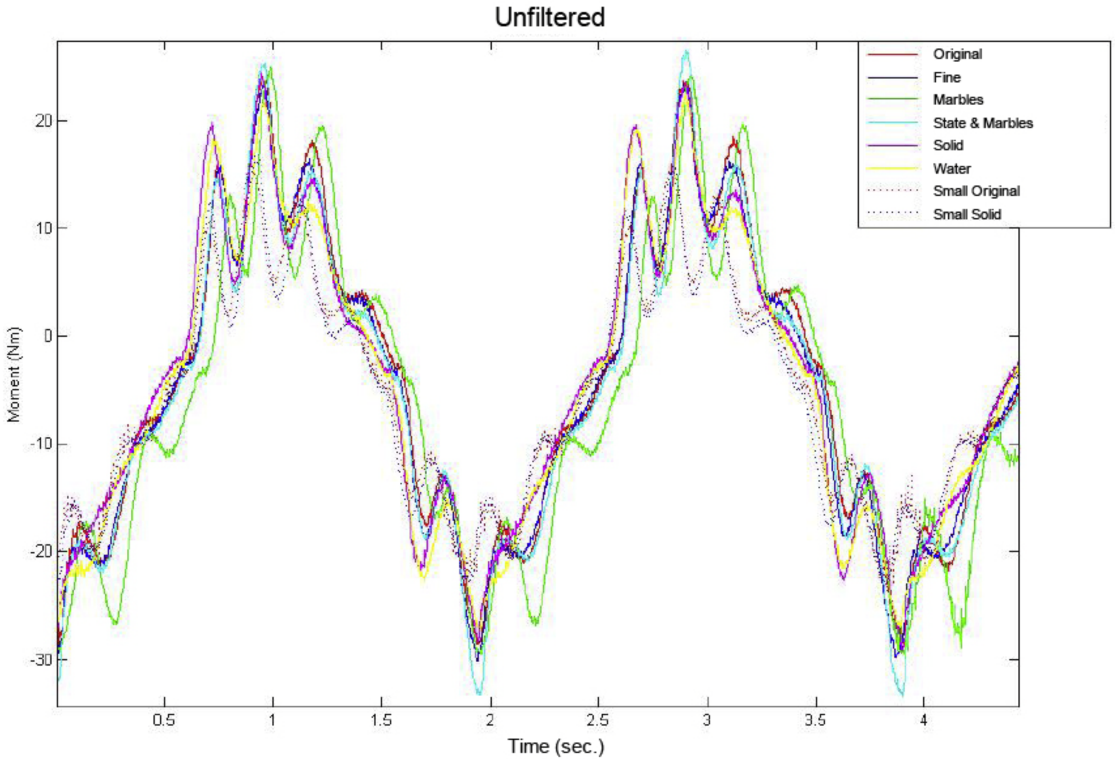
The tube trainer to be tested is attached to the mechanical arm. By turning on the motor, the arm is moved with an average speed of 1 m/sec, with an attendant change in the arm’s angle of 66°. Over a course of 15 seconds, the strain gauge signal will be measured and analyzed via the METLAB program. This procedure is repeated for every tube trainer being tested. The sequence of the testing is as follows:

1.	Original
2.	Solid
3.	Fine
4.	Water
5.	Marbles and Slate
6.	Marbles
7.	Original Small
8.	Solid Small

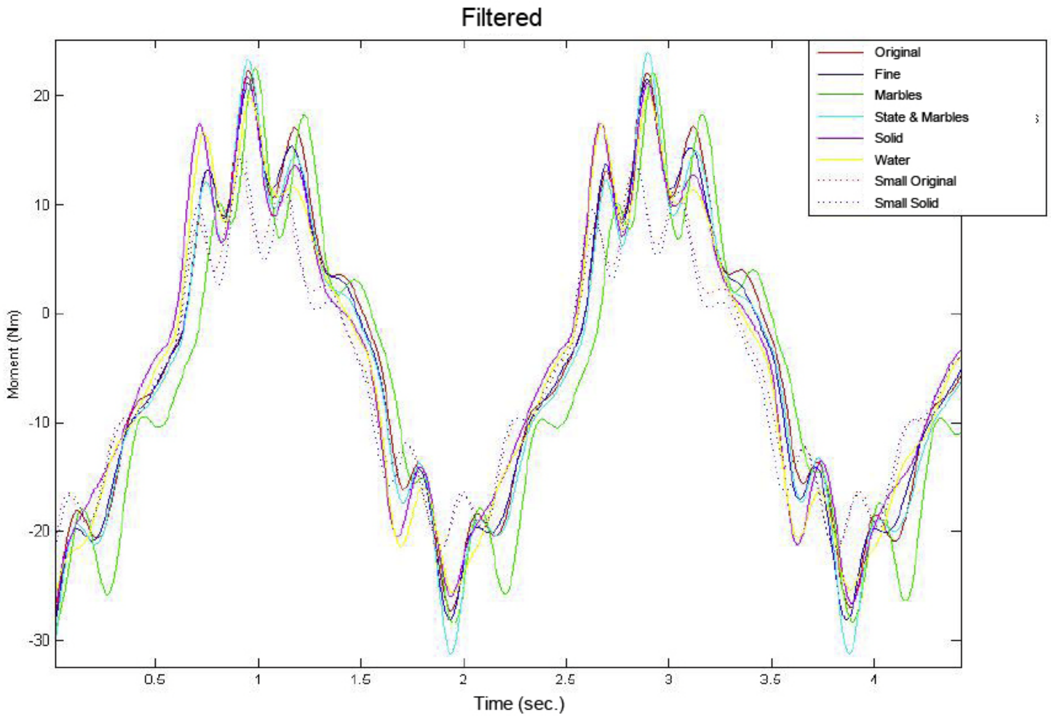
Data values are converted to the momentum observed at their pivot point. The results of the different test are synchronized, in order to draw comparisons between the different signals. In order to reduce sampling errors from the signal, a low-pass filter is used. Graphs were plotted of both the raw and the final data.

2. Test Results

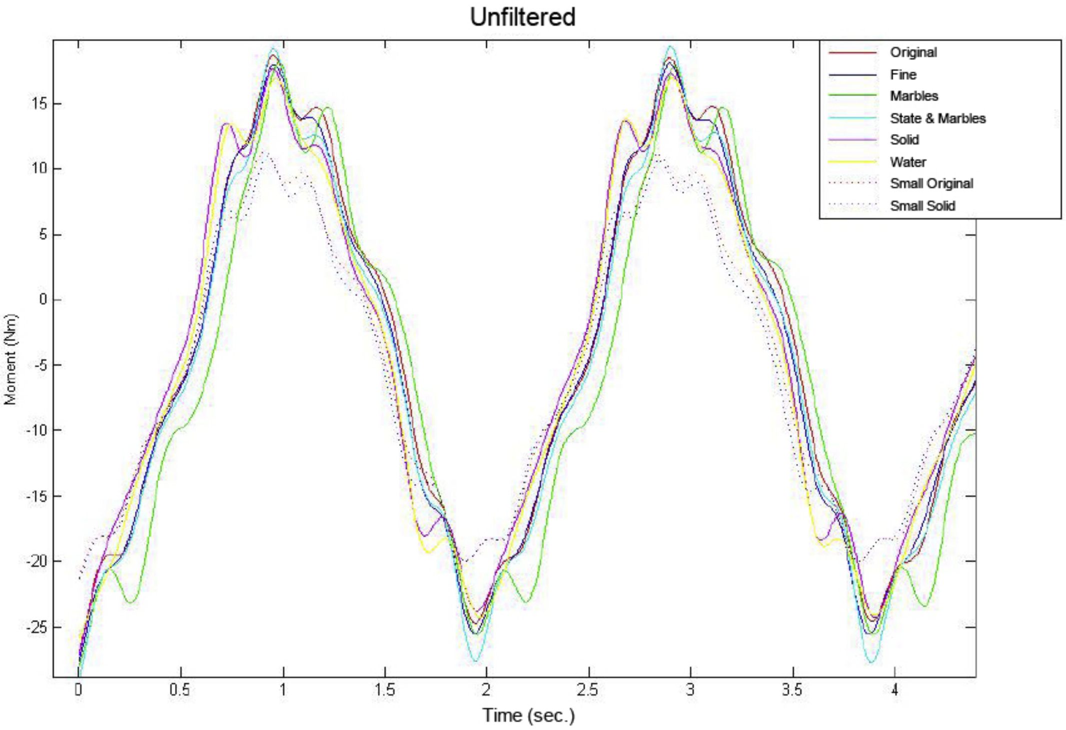
The test results are rendered in graphs. They plot the momentum in relation to time. The force impacted by the tube trainer on the lever arm can be deduced by dividing the momentum by the length of the lever (F = M/a). The following graphs show the results of all measurements. Side-by-side graphs with an unfiltered signal (raw data), a filtered signal and an optimized signal will be shown. In “Analysis of Test Results” only filtered data are being used. In the attached exhibits, unfiltered, as well as filtered and optimized data signals are provided.



Diag. 2.1: chart of the unfiltered signal of the different tube trainers



Diag. 2.2: chart of the filtered signal of the different tube trainers



Diag. 2.3: chart of the filtered signal of the different tube trainers

3. Analysis of Test Results

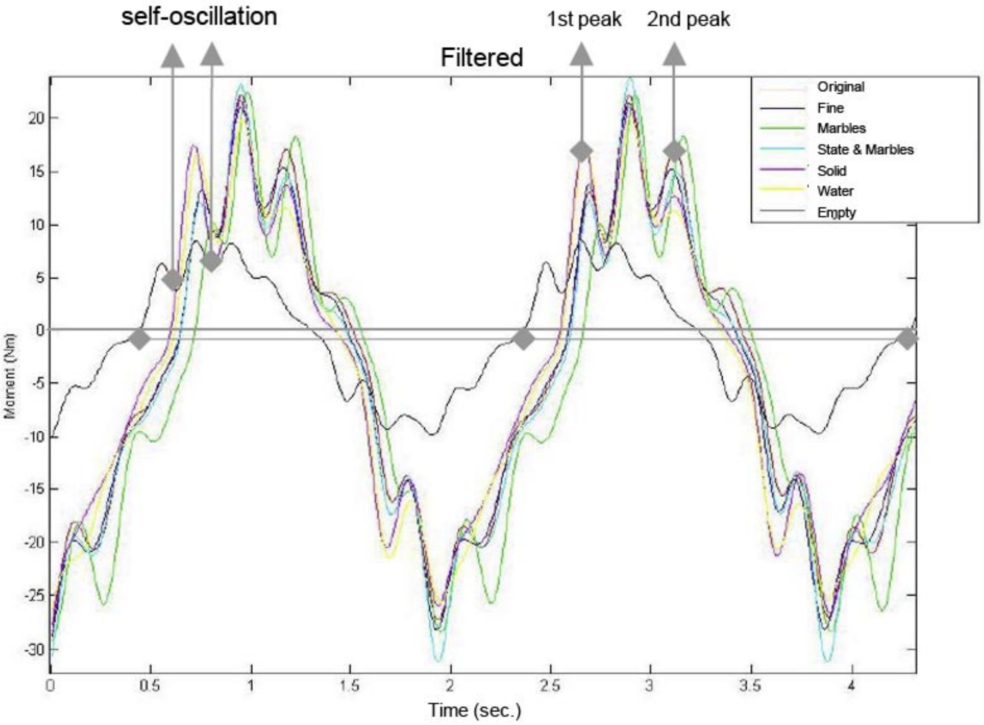
When analyzing the test results, it is important to read the signals correctly in order to obtain an accurate interpretation. Since the purpose was to compare the original slate granulate-filled tube trainer with different fillings, these were compared side by side. In this manner, a clearly laid out overview of the graphics was established. Furthermore we amplified the critical points, which allows for a more accurate interpretation. All comparisons are discussed in the following subsections.

3.1 Interpretation of graphs

Before one can draw a proper comparison between the different tube trainers, it is important to ensure that the graphs are being correctly interpreted. It is therefore essential to recognize the tube trainer's corresponding position to peaks in the chart. The following chart shows the test results of a 1.25 liter tube trainer and an empty tube.

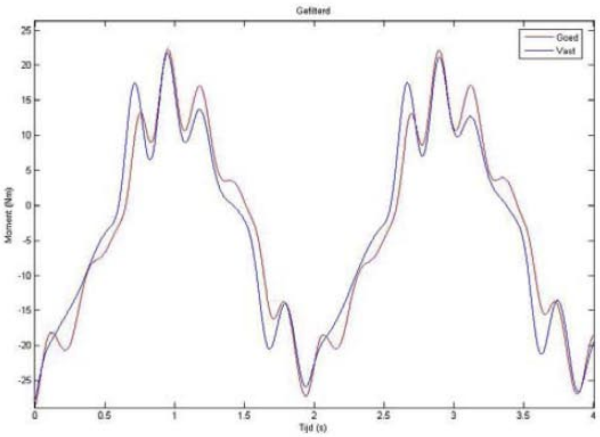
What is immediately noticeable is the recurring cyclical pattern. The starting point of the cycle is noted as the zero point. This is the point at which no force is being exerted on the tube trainer. The amount of zero force is the point where the lever arm does not accelerate or decelerate -- in other words, the point at which the arm's direction is reversed. In order to reverse direction, the tube's velocity must be reduced to zero before it can again be accelerated in the other direction. Due to the velocity still inherent in the tube's filling after the point of reversal, the strain gauge elongates maximally, resulting in maximal momentum. The tube's filling impacts after the change of direction, thus creating a second peak.

The chart, however, shows three peaks. This phenomenon is explained by the arm's own swinging motion. If the test is conducted without an attached tube trainer, the arm's own motion would still be recorded. The graph clearly shows that even without an attached tube trainer, three peaks develop. This can only be attributed to the arms own movements. It is of note that the cycles without an attached tube trainer are shorter than with a tube trainer. This is due to the fact that the motor applies a constant force to a smaller mass than one with a tube trainer, and thus a faster acceleration of the lighter lever arm is achieved (force = mass x acceleration).

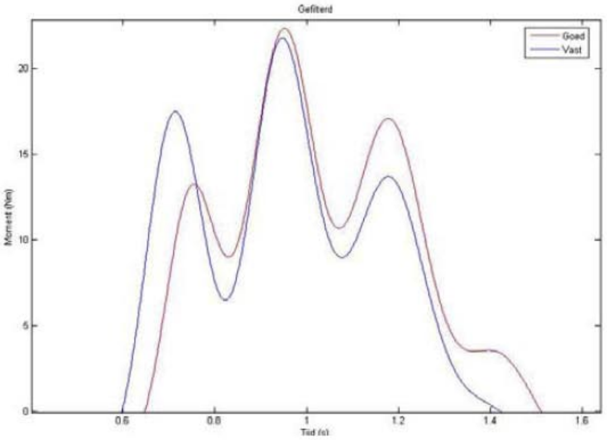


3.2 Original Tube Trainer in comparison to a Tube Trainer with a Solid Mass

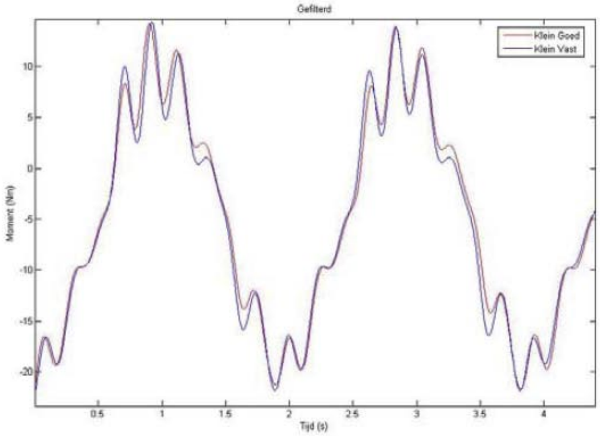
In the following graphs, the test results of the original tube trainer are compared with a tube trainer containing a solid mass.



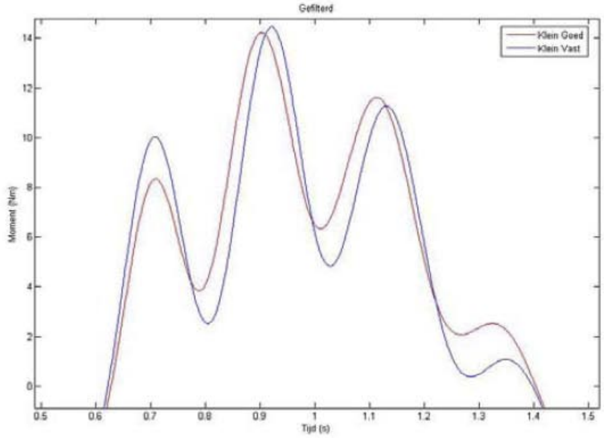
Diag. 3.2: graph showing the filtered signal of the original and solid 1.25 liter tube trainers



Diag. 3.3: enlarged segment of a graph showing a filtered signal of the original and solid 1.25 liter tube trainers



Diag. 3.4: graph showing the filtered signal of the original and solid .63 liter tube trainers



Diag. 3.5: enlarged segment of a graph showing a filtered signal of t he original and solid .63 liter tube trainers

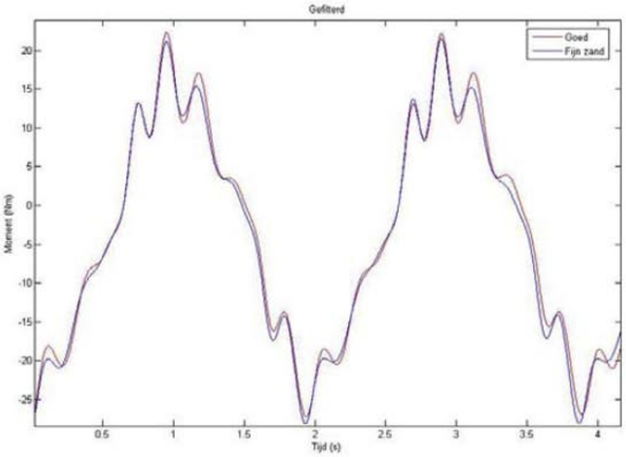
The fact that the first peak of the tube trainer with a solid mass is higher than the one of the original tube trainer with a slate-granulate filling is explained by the fact that the tube trainer with a solid mass has a higher weight than the tube trainer with the slate granulate at its moment of reversal. This difference in weight is caused by the granulate moving in empty space, at which moment that tube trainer could be seen as empty. As previously explained, the tube trainer's willing velocity must come to zero before it can again be accelerated into the opposite direction.

The force exerted by the tube trainer upon the arm determines the momentum. In other words: momentum = force x arm (M = F x A). Since the momentum of the solid tube trainer exceeds that of the original tube trainer with the slate granulate, its force must also exceed that of the original, since the lever arm is constant. The force imparted by the tube trainer to the lever arm can also be determined by the formula "Force = mass x acceleration" (F = m x a). A larger force of the tube trainer with a solid mass can therefore either be caused by its larger acceleration or its larger mass. Since the cycle times of both trainers are essentially identical, it is unlikely that the tube trainer with a solid mass accelerates faster than the original tube trainer. The difference must therefore be attributed to the respective mass' behavior at the point of direction reversal. The only explanation for this is that the original tube trainer is not as heavy at the point of directional change as the solid one, because at that point, the contents of the original tube trainer are temporarily suspended in mid-air.

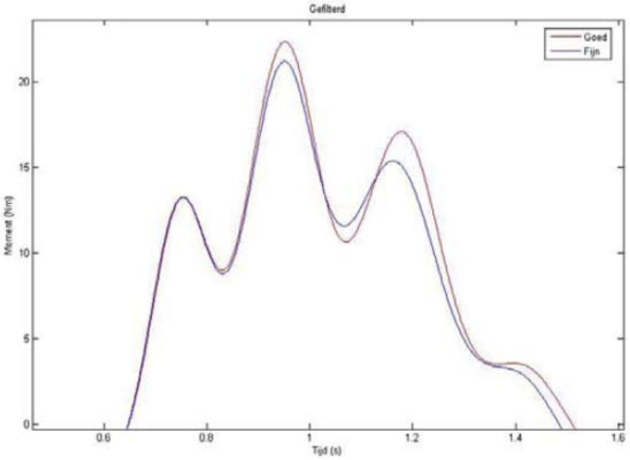
At the second peak the original tube trainer shows a higher momentum than the solid one. This is due to the fact that the shifting mass – which at the time of the first peak was suspended in mid-air -- now impacts on the tube trainer. Since this effect cannot occur with the inertia of a solid mass, it is logical that the second peak is higher for the original tube trainer than for the tube trainer with a solid content.

3.3 Original tube trainer in comparison to a tube trainer with fine slate granulate

The following graph compares the test results of the original tube trainer with a tube trainer containing fine slate granulate.



Diag. 3.4: Graph showing the filtered signal of the original and fine 1.25 liter tube trainers



Diag. 3.5: Enlarged segment showing the graph of the filtered signal of the original and fine 1.25 liter tube trainers

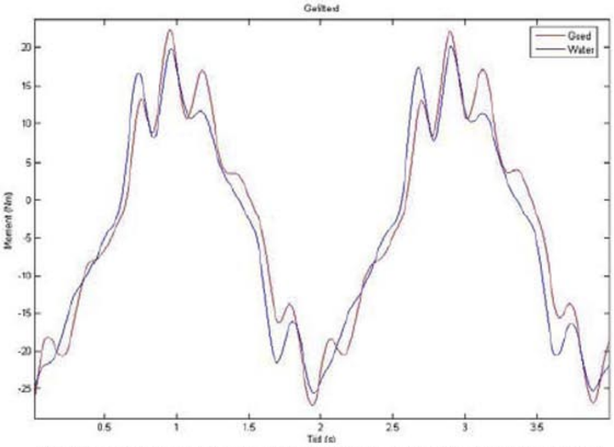
As previously demonstrated, the motion still inherent in the tube trainer at the pivot point must be reduced to zero before it can resume acceleration in the opposite direction. Through the still-existing speed in the tube trainer's contents after its point of reversal, the strain gauge is maximally elongated, resulting in maximal momentum. This peak, at a height of 13 Nm, is nearly identical for both the original and the fine slate granulate tube trainers. This can be explained by the fact that both tube trainers have an identical mass at their point of reversal. The fillings of both tube trainers are temporarily suspended in mid-air, during which point the tube trainers behave as if they are empty.

After changing direction, the contents of the tube trainers will impact, by which the second peak is created. This second peak is higher for the original tube trainer, showing a higher momentum for the original tube trainer. The force exerted by the contents of the original tube trainer is then also greater that of the tube trainer containing the finer slate granulate; after all, "momentum = force x arm" (M = F x Arm), by which the lever arm remains constant in both situations.

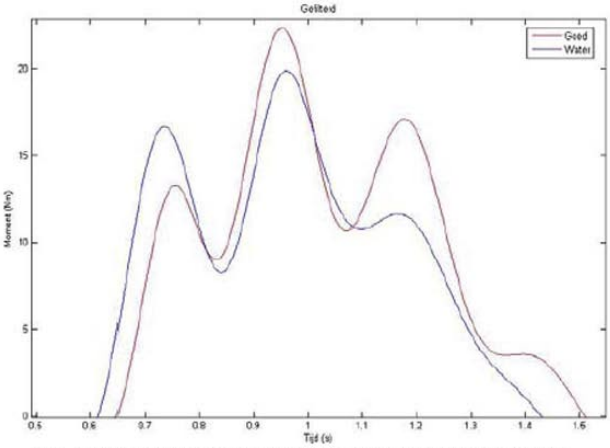
The difference must be caused then by the tubes' different contents. If one views the total filling in its individual parts, the granules of the finer slate filling differ in terms of weight from the granules of the original filling. Since the particles are being accelerated by the power of the motor, the lighter parts will have a higher acceleration than the heavier parts (M = F x Arm). Thus the lighter particles will shift more quickly to the top. As soon as the direction of the tube trainer is reversed, the lighter particles will impact, while the heavier particles will "take their time". Because the acceleration of the tube trainer is based on the lighter moving particles, it will already have a significant velocity, which will increase the overall impact.

3.4 Original tube trainer in comparison to a tube trainer with water

The following graph shows the test results of the original tube trainer in comparison to a tube trainer filled with water.



Diag. 3.6: graph showing the filtered signal for the original and water-filled 1.25 liter tube trainers



Diag. 3.7: enlarged segment of graph showing the filtered signal for the original and water-filled 1.25 liter tube trainers

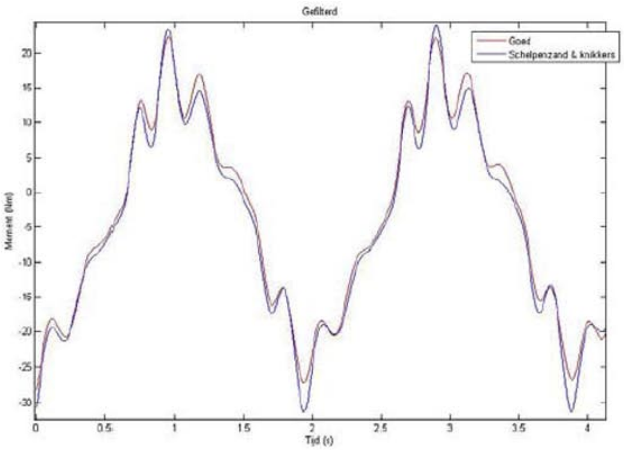
The fact that the first peak of the water-filled tube trainer is higher than the original tube trainer with slate granulate filling, can be explained by the fact that the tube trainer with water has a higher weight at its point of reversal than the original tube trainer. This difference in weight can be explained by the fact that the contents of the original tube trainer is suspended in mid-air, at which point it can be viewed as empty, while the water has adhesive properties by which it adheres to the tube trainer.

As previously explained, the velocity still inherent in the tube trainer must be reduced to zero before it can again be accelerated in the opposite direction. The force exerted by the tube trainer on the arm stems from its momentum. After all: "Momentum = Force x Arm" (M = F x A). Since the momentum of the tube trainer with water is greater than that of the original tube trainer with slate granulate, it follows that the force must also have been greater, since the arm's length remains constant. The force exerted by the tube trainer on the arm could also be determined with the formula "Force = mass x acceleration" (F = M x A). A greater force of the water-filled tube trainer can be accomplished either because it has a greater acceleration or a greater mass. Since the cycle time of both tube trainers is nearly identical, it is unlikely that the tube trainer with water accelerates faster than the original tube trainer. The difference must therefore lie in the respective masses at their point of reversal. The only explanation that would account for this is in the fact that the contents of the original tube trainer are temporarily suspended in mid-air.

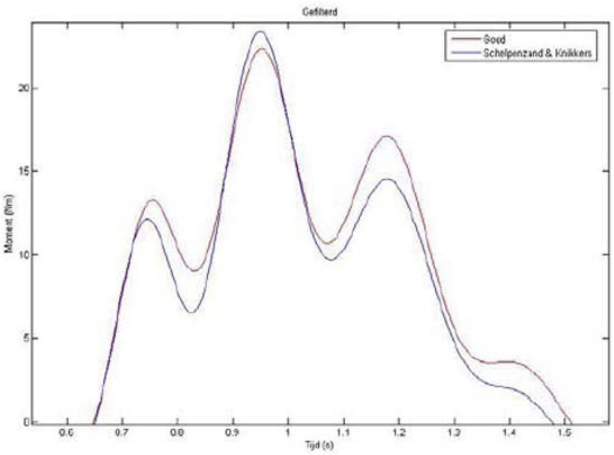
At the second peak the original tube trainer exhibits a larger momentum than the water-filled tube trainer. This is due to the fact that the mass, which in the first case was suspended in mid-air, now impacts against the tube trainer. Because such a delayed effect is hardly present in the water-filled tube trainer due to its adhesive properties, is it logical that the second peak of the original tube trainer is higher than that of the tube trainer with a fixed content.

3.5 Original tube trainer in comparison to a tube trainer with slate granulate and marbles

In the following graph, the test results of the original tube trainer are compared with those of a tube trainer filled with slate granulate and marbles.



Diag. 3.8: graph of filtered signal showing the original and slate/marble-filled 1.25 tube trainers

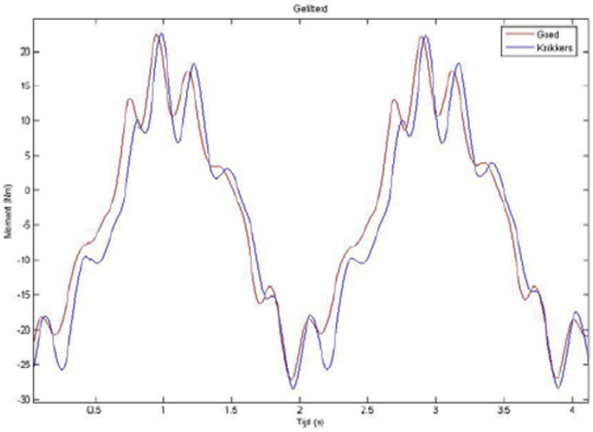


Diag. 3.9: Enlarger segment of graph of filtered signal showing the original and slate/marble-filled 1.25 tube trainers

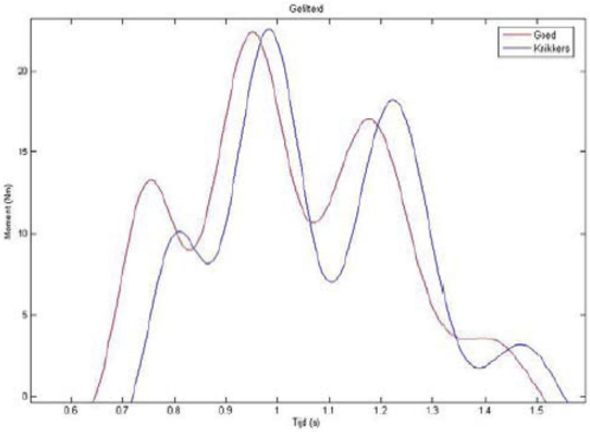
There is a minimal difference in the height of the first peak between the original and the slate granulate/marble-filled tube trainers. Since both tube trainers are filled with hard particles, one should expect that in both cases, the particles of the original, as well as the particles of the slate granulate/marble-filled tube trainer are temporarily suspended in mid-air. The difference is almost negligible, but could possibly be explained by the fact that the slate granules have a higher adhesive property than the marbles. Individual slate granules could have adhered themselves to the original tube trainer, through which a comparison between the original and the tube trainer will with slate granulate and marbles would be more difficult. Thereby the original tube trainer would be somewhat heavier at the time of the first peak, thus exhibiting a larger momentum.

3.6 Original tube trainer in comparison to a tube trainer with marbles

In the following graph the test results of the original tube trainer are compared to a tube trainer with marbles.



Diag. 3.10: graph showing the filtered signal of the original and marble-filled 1.25 liter tube trainers



Diag. 3.11: Enlarged segment of graph showing the filtered signal of the original and marble-filled 1.25 liter tube trainers

There is a difference in the height of the first peak between the original tube trainer and the marble filled tube trainer. Since both tube trainers are filled with hard particles, one would expect that on their reversal of direction, both contents would be temporarily suspended in mid-air. The difference could be ascribed to the fact that the slate granulate has a higher adhesive property than marbles. Individual slate granulate particles could have attached themselves to the original tube trainer's inner surface, thus making it heavier as compared to the marble-filled tube trainer. Thus the original tube trainer would be somewhat heavier at the time of the first peak, and therefore creating a bigger momentum.

If the graphs of the original tube trainer are compared to the graphs of both the marble-filled and the slate granule/marble mix tube trainers, the differences in the heights of the peaks are very clear. It is logical that the difference in peaks between the original tube trainer and the tube trainer filled with marbles is larger than the difference in peaks between the original tube trainer and the tube trainer with a slate granulate/marble filling. After all, in the tube trainer with the mixed filling, individual particles will also adhere to the tube trainer, which lessens the difference.

At the second peak the original tube trainer shows a smaller momentum than the tube trainer with marbles. One would expect that the opposite would be the case, since marbles, acting more like a solid mass, would have smaller peaks. The result could have been caused by the limited velocity of the lower arm. At higher velocities we would expect that the graphs comparing the original tube trainer with a marble-filled tube trainer would give an actively different picture. At the relatively low velocity, the marble will start moving only at a later point in time, thus exhibiting a different behavioral pattern than one might expect.

4. Conclusion

The tube trainer is essentially a tube partially filled with a freely moving mass. This moving loose mass generates an additional mechanical load at the beginning and end of each movement. This secondary effect should be especially beneficial to training the deeper connective tissues.

The tests have demonstrated that the effect is dependent on the properties of the material that moves freely inside the tube. Materials with high adhesive properties adhere to the tube trainer, thereby lessening the effect as compared to materials with a lower adhesive property. Furthermore, also the size of the particles has a small influence on the effect. Larger particles take longer to accelerate, but because the direction of the tube trainer has already been reversed and acceleration in the opposite direction has already been initiated, the impact is all the greater.

In summary it can be concluded that relatively heavy particles with low adhesive properties yield the most favorable results.

Center of Expertise in Motion Technology
& Office of Motion Technology Concepts