Resolution improvement on surface pressure data

Broeze, G.J.

Published: 01/01/2007

Document Version
Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:
- A submitted manuscript is the author's version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
Resolution improvement on surface pressure data

J. Broeze

DCT 2007.133

Traineeship report

Coach(es): Ir. R. van der Steen (TU/e)
Dr. Ir. I. Lopez (TU/e)
Ir. H. van Benthem (Vredestein)
Ing. B. de Bruijn (Vredestein)

Supervisor: Prof. Dr. H. Nijmeijer

Technische Universiteit Eindhoven
Department Mechanical Engineering
Dynamics and Control Group

Eindhoven, October, 2007
Summary

In order to develop a full car tyre model there is a need for a better friction model. Vredestein Banden BV, a tyre developer and manufacturer, has the knowledge and facilities to perform important experiments. In order to measure the contact surface pressure of car tyres, Vredestein is using a Tekscan sheet on one of their measurement systems. Tekscan is a company that produces hard and software which can be used to measure contact pressure. Currently Vredestein has another measurement system called the LAT100. The LAT100 is designed to perform small scale experiments indoor, yet under outdoor conditions. On the LAT100 a small rubber wheel is mounted which has, in this case, no tread. With the LAT100 however, it is not possible to measure the surface pressure. The small wheel is therefore mounted on a Tekscan system which unfortunately is not designed for such a small wheel. Because of this and the fixed resolution of the measuring system (Tekscan) the resulting resolution of the experiment data is too coarse to be used for validation purposes.

The goal of this report is to investigate whether it is possible to improve resolution of a contact pressure measurement using numerical techniques.

A possible solution to increase the resolution is by postprocessing the data numerically. A possible way to do this is by using data from multiple samples coming from one measurement. Using the fixed speed and sample rate it is possible to determine the place of every sample within one measurement. The rows of different samples are then placed successively creating a new sample with an improved resolution. It is however, difficult to fully computerize this process due to noise or incomplete samples. Raw data also needs to be normalized before conclusions can be given about the results. By using the total applied force, the surface on which it is applied and the total sum of the data, the results can be normalized into a contact pressure (Bar).

In order to check reproducibility, experiments were done with a single sample wheel. Using different initial conditions, the resulting maximum values of each measurement were compared. Therefor the average and standard deviation are used. There is a maximum difference of 25% between similar tests. This relative difference is expected to be caused by irregularities in the tread surfaces and a minor bit is expected to be caused by heterogeneous rubber structures. The rubber structure is again influenced by vulcanization and chemicals used to influence material proporties.

Furthermore, no tests are done regarding friction or possible shear stresses. Due to the slow and constant motion (0.04 m/s) during measurements, shear stress and friction is assumed to be constant and therefore not causing difference between similar tests. Moreover, these effects will be only of interest when the tread surface irregularities are ruled out.

For further investigation, two compounds were selected. A hard and a soft compound which, within Vredestein, are numbered 716 and 771 respectively. These compounds are vulcanized in a standard mould under a temperature and time specific to each compound. During vulcanization the rubber properties change due to changes on molecular level.

Eventually it can be concluded that it is indeed possible to improve the resolution. However, when enough samples are available and there is no need for an improvement in resolution, it is enough to just sum and average all samples. The latter has also the advantage of taking less process time and it is assumed to be no less accurate.
## Contents

1 Introduction .................................................. 5  
   1.1 Background ........................................... 5  
   1.2 Goal .................................................. 5  
   1.3 Approach ............................................. 5  

2 LAT100 and Tekscan ........................................ 8  
   2.1 LAT100 .................................................. 8  
   2.2 Tekscan ............................................... 8  

3 Reproducibility Tekscan .................................... 11  
   3.1 Calibration ........................................... 11  
   3.2 Normalization ......................................... 11  
   3.3 Velocity ............................................... 12  
   3.4 Tread .................................................. 12  
   3.5 Texture ............................................... 12  
   3.6 Tests ................................................... 14  

4 Data processing method to improve the resolution .... 17  
   4.1 Pick and place method ................................ 17  
   4.2 Advantages with respect to sum and average ....... 19  

5 Measurements ............................................... 22  
   5.1 Compound selection .................................... 22  
   5.2 Raw data ............................................... 23  
   5.3 Results improvement ................................... 23  
   5.4 Comparing with summing and averaging .......... 23  

6 Conclusions & Recommendations .......................... 27  
   6.1 Conclusions ........................................... 27  
   6.2 Recommendations ...................................... 28  

A Matlab preprocess. Determines contact area and improves resolution by using other Matlab programmes .... 30
B  Determine boundaries contact surface area  
C  Improve resolution  
D  End process. Normalization and sum and average all improved samples  
E  Convert '.asf' file into Matlab matrix
Chapter 1

Introduction

1.1 Background

In the current development of car tyres, noise and wear are very important subjects but are still difficult to predict during the early stages of development. Furthermore, relative simple models only predict results in a limited range of use. CCAR, a partnership initiated by TNO, brought together some prominent parties in the Dutch automotive industrie. One of CCAR’s projects is the development of a state-of-the-art FEM tyre model. This is also the doctoral assignment for Ir R vd Steen from the TU/e (Technische Universiteit Eindhoven).

In order to develop a full car tyre model there is a need for a better friction model. Vredestein Banden BV, a tyre developer and manufacturer, has the knowledge and facilities to perform important experiments. In order to measure the contact surface pressure of car tyres, Vredestein is using a Tekscan sheet on one of their measurement systems. Tekscan is a company that produces hard and software which can be used to measure contact pressure. Currently Vredestein has another measurement system called the LAT100. The LAT100 is designed to perform small scale experiments indoor, yet under outdoor conditions. On the LAT100 a small rubber wheel is mounted which has, in this case, no tread. With the LAT100 however, it is not possible to measure the surface pressure. The small wheel is therefore mounted on a Tekscan system which unfortunately is not designed for such a small wheel (figure 1.1 and 1.2). Because of this and the fixed resolution of the measuring system (Tekscan) the resulting resolution of the experiment data is too coarse to be used for validation purposes.

1.2 Goal

The goal of this report is to investigate whether it is possible to improve resolution of a contact pressure measurement using numerical techniques.

1.3 Approach

This report describes a possible solution to increase the resolution by postprocessing the data numerically. A possible way to do this is by using data from multiple samples coming from one measurement. Because the speed and sample rate during the measurement are known, it should be possible to combine data from more samples. By extracting data from multiple samples and combining this data, making one new sample, it should be possible to get an improved resolution. In order to improve the resolution Matlab will be used to process the data. However, because many
measurements are used, the reproducibility is also investigated by comparing measurements with different initial conditions. If the approach proves to be useful, more experiments with different compounds will be performed. These results can then be used to validate a FEM model of the small rubber wheel.

This report is organized as follows. In Chapter 2 an introduction is given of both the LAT100 and the Tekscan. In Chapter 3 the results are given regarding the reproducibility. In Chapter 4 the numerical technique is explained that is used to improve resolution. In Chapter 5 information about the compound selection is given as well as the results of the measurements and the numerically improved data. In Chapter 6 the main conclusions and recommendations of this research are summarized.
Figure 1.3: Picture of small rubber wheel (LAT100 tyre, diameter 80 mm and width 20 mm).
Chapter 2

LAT100 and Tekscan

For this research the small rubber wheel normally used on the LAT100 is mounted on the Tekscan system. This wheel has a diameter of only 80 mm and a width of 20 mm. The LAT100 should represent outdoor conditions on a small scale, and with the Tekscan machine the contact pressure is measured. In this chapter a small introduction in the working principles of both machines is given.

2.1 LAT100

The LAT100 is a test machine developed by Dr Grosch [3]. The main part of the machine can be seen in figure 2.1. Several parameters such as velocity, normal force, slip angle and different contact surfaces can be adjusted. It is possible to measure the side, lateral and normal force and the velocity. On this machine a small rubber wheel is mounted that is fixed in all directions except for the rolling direction. It is then placed on a disk with a certain surface texture. During a measurement this disk is set in motion and thereby drives the rubber wheel. This machine is mainly used to rank different compound relatively with respect to wear, rolling resistance on dry, ice and wet grip. The white disk (see figure 2.1) can be replaced by other disks having different texture profiles. It is also possible to heat or cool down the disk within a certain temperature range and it is even possible to place a disk with a small ice ring (shown in figure 2.1). To investigate wet grip conditions, it is possible to wet the surface by putting a water beam close to where the rubber wheel touches the disk. Therefore the water hose (moveable) is used which is also shown in figure 2.1. Under dry conditions it is common to add powder close to the contact surface. This keeps the disk from getting filthy and losing its specified texture due to lost rubber particles from the rubber wheel. The powder should also represent the dirt that is commonly found on the road. In the ideal case this machine should predict which compound performs best in outdoor tests.

2.2 Tekscan

The Tekscan machine is able to give information about the contact pressure between a tyre and a flat surface. In this machine a flat glass plate (figure 2.2) moves with a constant velocity. On the plate a Tekscan sheet [4] is mounted (figure 2.3). This sheet consists of vertical and horizontal wires that measure a difference in electrical resistance corresponding to the amount of pressure at that point where the wires make contact. With a known normal force this electrical resistance can be computed to a contact pressure load. Every time a sample is taken, a matrix is filled with numbers corresponding to the electric resistance. This matrix has the same dimensions as the Tekscan sheet. The rows and columns of the matrix correspond to the horizontal and vertical
wires of the Tekscan sheet. Every cell in the matrix represents the point on which these wires make contact. As a test is done, the rubber wheel rolls over the sheet in approximately 10 seconds. With a sample frequency of 25 Hz, 250 samples (matrices) are taken. The Tekscan machine is normally used for testing normal car tyres in a various sizes. The equipment is therefore some what oversized regarding the small rubber wheel. This results in a contact area of less then 10 by 17 mm, considering even a high load of 10 kg. Because the Tekscan sheet has a fixed resolution of 1.52 mm, this contact area has a maximum grid of 6 by 11 (length widthwise). In a meeting at Vredestein banden BV it was concluded that, in order to get a reasonable improvement, the 6 points in length needed to be at least 2 or 3 times higher. Of course increasing the load would compress the rubber more and result in a bigger contact area. But because the total load needs to be equivalent to every day passenger car values this is not realistic and therefore impracticable. Increasing the size of the wheel is not considered because it needs to fit in de LAT100 machine, which has a predefined wheel size. There is a Tekscan sheet available with a finer resolution but this is an expensive alternative since the finer resolution also needs different software. The model 5026 has the finest resolution available and surpasses the current one (8050, figure 2.3) with 2.4 times. Yet its dimensions (66 by 56 mm) make it unsuitable to measure the complete contact surface of car tyres. Purchasing this product would cost approximately $6000,- (£4500,-) including software and one Tekscan sheet.

This model will work on the hardware available at Vredestein Banden BV.A sample is nothing more than a matrix filled with not normalized values. It represents the image of the Tekscan sheet. Every cell in the matrix represents a point on the Tekscan film where a horizontal and vertical line cross. These values can be normalized using the known load. The Tekscan can measure up to a sample frequency of 25 Hz. Because of hardware and software limitations the sample rate cannot be higher than 25 Hz or more accurate than one decimal.

The Tekscan cannot deal with shear stresses. Slip or slip angles and accelerations should therefore be avoided. Longitudinal slip is assumed to be zero because of the low and constant velocity of the machine.
Figure 2.2: Tekscan machine with small rubber wheel.

Figure 2.3: Tekscan sheet (model 8050) rolling direction of the wheel is over the width.
Chapter 3

Reproducibility Tekscan

Before measurements are performed, the Tekscan sheet is equilibrated. This means a compound is placed on the Tekscan sheet and is placed under a load. Because the load is known it is possible to calibrate each point on the sheet. This gives the certainty that the Tekscan sheet again measures the same at every pixel.

Focussing on the Tekscan, measurements were performed in order to compute reproducibility. Meaning that with one rubber wheel multiple tests were performed. Forward, backward, with 5 and 10 kg normal weight, and with the wheel mounted left and right of the hub. In the ideal case, except for a different normal force regarding the 5 and 10 kg, this should lead to one and the same pressure distribution. However some parameters could lead to deviations in the results. The parameters that were investigated are the velocity, the tread and the rubber texture of the wheel.

3.1 Calibration

The calibration method of the Tekscan can be found in [1]. Hereby the Tekscan sheet is placed in a mould together with a windbag. When the windbag is inflated, it sets a pressure on the total surface of the sheet. When a certain pressure is obtained, the total sum of the raw data is measured. The sum of the data, together with the total surface on which it is applied are used to determine a calibration factor.

3.2 Normalization

The calibration has a problem. Due to the fact that a specific compound is used, the calibration can not just be used for any compound. The Tekscan only measures on the grid points and with a known load and compound this is used to calibrate for the pressure on the area in between the points. Because of differences between compounds a force on one compound does not cause the same surface pressure as on another compound. To some point different compounds can be compared, but differences of up to 30% are no exception. It is therefore needed to normalize the values for different compounds. With a known force, a known surface and the data from a sample, it is possible to normalize the values. See for example figure 3.1. This shows three figures. Figure 3.1(a) shows the sample in its original scale. Figure 3.1(b) shows the same sample, only this time it zoomed in on the contact area. The colorbar on figure 3.1(b) shows a scale from 0 to more than 50. Now the data of this figure is normalized. This means that all the values are summed. The total of the sum is then divided by the total force that acts on the wheel, which is in this case 100 Newton (10kg*g, with g = 10 m/s²). Now the original data is divided by the normalization
factor and afterwards divided by the surface. At last the data is scaled from Pascal to Bar and this result is presented in figure 3.1(c). The following formula shows the computation as explained before:

\[
\text{original matrix} / (\text{total sum} / \text{total force [N]} / \text{surface [m}^2] / (1e5 \text{-[-]}) = \text{normalized matrix}
\]

### 3.3 Velocity

The surface on which the Tekscan sheet is mounted should have a constant velocity. The velocity can be measured easily using just a stopwatch and a ruler. Because of the long trajectory of the glass plate (1800 mm) and its slow motion, this type of measurement is not less accurate with respect to a calibrated (and time consuming) test. 10 measurements gave the following results.

- average speed = 0.04089 m/s
- maximum deviation = 0.88%

### 3.4 Tread

A more difficult to measure parameter is the variance in height of the tyre tread. Although not visible, small deviations lead to unsymmetrical pressure distributions and local pressure peaks and dips. Vredestein Banden BV has a test machine available for measuring surface texture. However, this machine is calibrated for car tyres. Because of the range of the used laser it needs a different setting for the little rubber wheel. To reset this machine takes time and is not cost-effective for just one different size tyre. Therefore a less full-scale but, simple test is done. Using a turning lathe and a micrometer, the deviation in height is measured on three places (see figure 3.2). All regarding the total circumference on the left, right and center of the tread. This gave the following result.

\[
\text{Deviation in height of tread} = 5 \cdot 10^{-5} m
\]

The relative error between the deviation in height and the compression caused by a load on the wheel is not available, because it was not possible to get a good measurement of the amount of compression under certain loads. A possible solution is to test this with the FEM model or, with more effort, a tensile testing machine can be used.

### 3.5 Texture

Even more difficult to measure is the local rubber structure. Even though the rubber wheel consists of just one compound, 100 % homogenous material exists only in theory. Especially during vulcanization locally different pressure and temperature result in a heterogenous rubber structure. This causes the rubber to have locally different stiffness (and damping), again causing possible variance in the contact pressure.
(a) Original picture of sample from measurement (total Tekscan sheet view).

(b) Original picture zoomed in on contact area.

(c) Picture after normalization (Bar).

Figure 3.1: Example normalization for compound 771 with 10 kg load
3.6 Tests

Last but not least there is the reproducibility of the measuring system. Under the low and constant speed (0.04 m/s), a zero slip angle and an average pressure load, it is assumed that there is no longitudinal or lateral slip. Using one compound, multiple tests were done to investigate reproducibility of the Tekscan. Using one and the same rubber wheel, tests were performed under 5 different initial conditions.

- Moving forward
- Moving backward
- 180° with respect z axis (figure (3.3). (forward and backward)
- Turned approx 180° with respect to y axis (figure (3.3) (forward and backward)

Fortunately the circumference of the rubber wheel is just a bit smaller then the Tekscan sheet. Rolling the rubber wheel over the sheet means the result is approximately one time the circumference. Summing all the results should therefore always be the same because all peaks and dips should appear always but only just one time. Especially when rolling the rubber wheel forward and backward the results should match.

In order to compare different tests the average and standard deviation of the maximum values are used. During a measurement, every grid place on the Tekscan sheet can be used multiple times. After all the samples are taken a lot of data is recorded but in this case only the maximum values will be used. If the maximum values are represented in a picture the result is a path with maximum values. The results can be seen in figure 3.4. In all the pictures the width is not that of the complete matrix, but further to the left and the right only zeros are measured and are therefore not shown.

In theory all the results should be the same. However after the tests were done the result were different. Because of the fixed movement, the rubber wheel always rolls over the same
Figure 3.3: Wheel y and z axis.

Figure 3.4: Comparing maximum values of Tekscan data (716, hard compound).
place of the Tekscan sheet. Therefore these matrices can easily be divided by one another. To compare the results of the different initial conditions the results were divided on one another. When both results are the same this leads to an outcome of only ones. As can be seen in figure 3.4 the results after dividing are not only ones. One means that the maximum values have a perfect match. However, figure 3.4 gives only a first visual impression. To get a better indication of reproducibility these measurements can be compared numerically. To just compare all the data does not give a good overview. Contrary to just comparing the sum of all values which has no detailed information any more. To still have some detailed information, without losing the overview, these results are processed per column of the matrix. The columns are indicated in figure 3.4 from 0 to 25. From the columns the average and the standard deviation are computed. Those are again divided by one another. In this way a relative ratio between the average and the standard deviation is obtained. Thus the following is computed per column: standard deviation(1st test/2nd test)/ average(1st test/2nd test). In theory this number would be 0 because there would be no deviation in the maximum pressure along a column. Because the measurements show otherwise, this number gives information about the relative error between the average and the deviation of the maximum pressure. Because in theory it would be 0, this number gives information about the error between theory and the practical results. The results can be found in table 3.1. However, this number is just an indication and is not a general used number for indicating errors on this experiment. So care should be taken when this number is compared to errors of other tests results.

| Moving forward/Moving backward | max 10% |
| Left mounted/Right mounted     | max 25% |
| Moving forward/Turned approx 180° | max 25% |

Table 3.1: Reproducibility. Maximum relative error (standard deviation)/(average) of columns.
Chapter 4

Data processing method to improve the resolution

In this research a data processing method is proposed. Before this method can be used, the raw data from a Tekscan measurement is read by a Matlab file [5] which can also be found in appendix E. This file converts the Tekscan '.asf' file into a Matlab matrix that can be used for further processing. After the data is being converted, a second processing file is used to filter out all unneeded data (see appendix B). This means that only that part of the matrix is used that really made contact and thereby has data greater then zero. The rest of the matrix consists out of zeros or noise. A more detailed explanation of this processing can be found in [2]. After processing the raw data, the numerical method will be used to improve the resolution (see appendix C). The results of this method can be compared to those of a more ordinary solution. This way it is possible to prove the usefulness of the data processing method. By just summing and averaging all samples of the measurement a quick solution is found. However this solution does not improve resolution. It also does not have much certainty regarding the placing of every sample and could therefore be less reliable.

4.1 Pick and place method

By 'picking' specific data from multiple samples and 'placing' them into one new sample, a higher resolution is obtained. Therefore this method is called 'pick and place' (see appendix A). Figure 4.1(a) shows locally how the Tekscan sheet takes samples. Because of a difference in velocity of the glass surface and the corresponding sample rate there is a slight difference in every measurement regarding the same contact area. This is also shown in figure 4.1(a). This figure shows an example regarding a small piece of the contact area (gray) and four samples in succession. As the surface moves and drives the wheel, the gray area stays on the same place. The gray area is not a piece of the wheel nor is it a piece of the surface. It is just a window with which the method can be explained. The length of the gray area represents the distance between two wires in the Tekscan sheet, the resolution. It can be seen that every sample measures a different point on the contact area. When the first sample is taken the right side, or beginning, of the gray area is measured. At the second sample the grid of the Tekscan sheet is shifted with respect to the area and therefore it is not the beginning of the area that is measured. Instead the point that first measured the begin of the area now measures a little left inside the gray area. Now a second point is measured within the gray area. Between the second, third and fourth sample the grid of the Tekscan sheet is again shifted. The fourth sample measures just before the end of the area. In theory it is possible to measure every place within the gray area if the sample rate (or the speed of the surface) could be adjusted according so. It would then be possible to take the second sample...
wherever wanted. In this case the area would be divided in three pieces so that the resolution would improve accordingly.

However, in practice it is impossible to take samples that quick. It is even impossible to take the second sample within the gray area. It is not the same row that shifts underneath the area. The first point corresponds to the first row of the first sample. The second point however, corresponds not to the first but the second row of the second sample. The third point again corresponds to the third row of the third sample. The fourth and last point in the figure is represented by the fourth row in the fourth sample. This can be explained by the speed of the surface (0.04089 m/s) and the sample rate (25/s). Simple computations give the following result:

\[
\frac{\text{Grid spacing [m]}}{\text{Velocity surface [m/s]}} = \frac{0.001524}{0.04089} = 0.03727s
\]

\[
\frac{1}{\text{Maximum sample rate}} = \frac{1}{25} = 0.04s
\]

\[
\text{Velocity surface [m/s] \times 0.04 = 0.0016356m}
\]

\[
0.04 - 0.03727 = 0.00273s
\]

\[
\frac{\text{Samples in succession within area}}{0.00273} = 14.97
\]

This results in the fact that, regarding the tekscan sheet, it moves 0.0016356 m between every sample. Because this is more then the distance between two successive points on the Tekscan sheet, being 0.001524 m, the gap between two samples is larger then the resolution of the sheet itself. This can be seen in figure 4.2. In this figure we follow the dot as the dot is the measuring point. This means only one measuring point is explained. In practice the same can be done for many points but in this case the picture would become too detailed and loose its overview. The white spots represent the resolution of the Tekscan sheet. When the sample rate could be adjusted as pleased the dot could be placed on any place wanted. Instead it measures as can be seen in the figure. The first measurement, also being specified with the number one, is at the beginning. Considering only the line with the dot it can be seen that the second measurement is outside the area between two measuring points. However, by using successive points it is still possible to get information within the grid (gray) area. And as the the calculations before show, it is possible to get 15 (exactly 14.97) samples in succession of one area. Meaning that there is a possibility to improve resolution by a factor 15.

It would be convenient when the contact area was divided exactly by a set of predefined number of samples. Unfortunately, the sample rate is restricted. Not only by a maximum of 25.0 per second, but it is only possible to enter one decimal for the sample rate. If the sample rate could be adjusted more precise it would be possible to measure maybe a few samples of one measurement exactly on the same place of the wheel. These samples should theoretically be the same and could therefore be used to evaluate results and errors. But even within 250 samples there is not one sample that exactly equals another sample. However, having each sample on exactly the same place would not be convenient. It would then be impossible to improve resolution because every sample would measure the same points on the contact area.

Still regarding the small gray piece of the contact area, figure 4.1(b) shows the result of the four samples. The figure shows only that part of the sample that represents the contact area. The black part represents the total contact area and the gray part represents the gray part as in the previous figure. The rest of the matrix, that is not shown, only contains zeros because there is no contact (pressure) at that area. As the figure shows four times the contact area, the dotted line shows the place where the measurement takes place. This is used to select multiple samples and combining them into one new sample. Figure 4.1(b) and 4.1(c) show how multiple samples are combined into a new sample. The solid grid represents the samples. The dotted line represents a succeeding row in a succeeding sample (matrix). Figure 4.1(c) shows figurative how the samples
are combined. The samples are placed on top of each other keeping the contact area as reference. Now a new matrix is made. To fill this matrix, the first row is taken of the first sample, the second row of the second sample, the third row of the third sample and finally the fourth row of the fourth sample. In the same order these rows fill the new matrix. This results in a better resolution which is also shown in figure 4.1(d). The number of rows that can be used depend on the speed and sample rate of the Tekscan sheet. In this example only 4 samples are used because an equal fifth sample would exceed the gray contact area. In the experiment it is possible to use a maximum of 15 samples. Since that is not needed some data can be summed and averaged to improve smoothness, again leaving the new sample to be 3 times better in resolution. Obviously, 15 samples in a total of 250 lead up to more then just one new sample. Combining and averaging all those samples again lead up to the results treated in chapter 5. Because of the number of samples (around 250) it is impossible to compute this by hand, therefore a Matlab programm is used to automatically find the proper matrices and placing the different rows with data into a new matrix. In case of 15 samples, Matlab picks the first sample and its first rows. It then follows the procedure as explained before, only for 15 succeeding samples and rows. Just combining matrices however, is not enough. Because of pressure peaks and dips the resulting matrix is not smooth. The measurements may not always exactly take place on the assumed piece of rubber. A possible explanation is that on a smaller scale the rubber is not smooth. Figure figure 4.3 shows an example of the possible texture when zooming in on the surface of the Grosch tyre. When a sample is taken it is unknown if the measurement takes place on a peak or a dip or somewhere in between. This could explain the difference between two samples even if they were expected to be the same.

4.2 Advantages with respect to sum and average

The 'Pick and place' method has a preference when it is needed to have a better resolution. However, it seems that for validation it is not necessarily needed. For it is not the resolution that gave unusable results, but it was probably the texture of the tyre that give a single sample to be useless for validation. The more samples used the more the result begins to look the result when data is only summed and averaged. Nevertheless care should be taken with summing and averaging. This method does not take care of the fact that succeeding samples do not lie in line regarding the same contact area. When all the samples are just summed and averaged it could be that the rows that are summed actually do not represent the same place of the contact area. The less samples used the less smoother the result. Which method should be used is still to be discussed. Both can therefore be used for validation with FEM, but when more accurate results are needed the 'Pick and place' method is advised. This method however takes more time to compute and is more sensitive for noise in the results.
(a) Step 1, example measurement taking 4 samples.

(b) Step 2, pick specific rows to be used in one new sample.

(c) Step 3, place rows successively in new sample.

(d) End result, one new sample with improved resolution.

Figure 4.1: Procedure resolution improvement
Figure 4.2: How the sample rate influences the place of a measuring point.

Figure 4.3: Possible tread surface and measuring points on what is theoretical the same place.
Chapter 5

Measurements

5.1 Compound selection

Vredestein Banden BV indicate different compounds using a 3 digit number. Two compounds are selected. The 771, being a soft compound, and the 716, being a hard compound. These compounds where chosen for there relative big difference in material properties. This is a commonly used test principle to rule out possible overlap of the results, especially when there are no previous results at hand. Except for 2 homogeneous tyres, 2 hybrid tyres are used. This involves 2 tyres with the tread layer being different from the inner tyre. In other words, 1 tyre holds an inner compound of 716 and just an upper layer of 771 and the other way round. These samples are chosen to investigate the influence of the inner stiffness. Eventually 4 tyres where tested which can be found in table 5.1

Normally rubber is vulcanized under the temperature and time specific to its compound [6]. During the vulcanization process the compound will get cross links on molecular level and therefor changing the rubber proporties (for example making it harder). However the vulcanization of two compounds leads to a problem. Some compounds disintegrate when the vulcanization process has the wrong temperature or duration. In this case the softer compound (716) does not meet its normal proporties when heated to 160 °C. The harder compound (771) however, fully vulcanizes without disintegration when heated to 140 °C for 33 min. Therefore the hybrid tyres are vulcanized at the rate of the compound 716. However, the time and pressure is only related to the vulcanization level. Other chemical reactions are not taken into account. Although no solid conclusions can be given, some can be said regarding compound composition. Difference in certain fabrics cause problems. Especially oil substances and some chemicals tend to diffuse. Of course the bigger the difference between compounds the more diffusion takes place. Experience gives some information about the substances that tend to diffuse the most. Comparing the most important substances, 716 and 771 differ between a ratio of 1.25 and 1.85 percent. As this is no aspect regarding this report more test are advised on using multiple compounds. The hybrid tyres have

<table>
<thead>
<tr>
<th>Compound</th>
<th>Vulcanization Time [min]</th>
<th>Vulcanization Temperature [°C]</th>
<th>Vulcanization Pressure [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>716</td>
<td>16.5</td>
<td>160</td>
<td>335-340</td>
</tr>
<tr>
<td>771</td>
<td>33.0</td>
<td>140</td>
<td>335-340</td>
</tr>
<tr>
<td>716/771</td>
<td>33.0</td>
<td>140</td>
<td>335-340</td>
</tr>
<tr>
<td>771/716</td>
<td>33.0</td>
<td>140</td>
<td>335-340</td>
</tr>
</tbody>
</table>

Table 5.1: Vulcanization parameters used on the selected compounds.
yet another problem. Because of the mould and the high pressure that are used to vulcanize, the thickness of the tread layer is limited. Layers thinner than approximately 2 mm cause problems because of flow. Even when measured and placed carefully, a small tread layer will flow outside, or forced together with the inner compound. This effect is not (fully) tested and therefore care should be taken with conclusions about corresponding results.

5.2 Raw data

Figure 5.1(a) and 5.1(b) show two random selected samples from measurements with 5kg normal weight. The resulting average pressure loads in this case are related to every day passenger car loads.

\[
\text{surface pressure load on average car tyre} = 5 - 8 \text{bar}
\]

The pressure is normalized with the known 5kg that is used as total weight. Figure 5.1(a) shows the results of the harder compound (716). This can clearly be concluded because of the smaller contact area due to a smaller compression. Also the maximum pressure is higher because the total weight is divided on a smaller contact area. These figures however, do not give the exact dimensions of the contact area due to the resolution of the Tekscan sheet. Comparing 5.1(a) and 5.1(c) the contact area does not increase 2 times. This again results in a higher pressure load which can be noticed by comparing the colors. Comparing the double compound tyre in figure 5.1(e). It can be seen that the dimensions of the contact area as well as the pressure load lie somewhere in between that of the 716 and the 771.

5.3 Results improvement

Figure 5.2 shows the results of numerically improved resolution after using the ’Pick and place method’. Contour plots are used for a better overview. The colors are all normalized on the same value. The figures clearly show that the 716 (hard) compound has a higher pressure load than the 771 (soft) compound. The figures also show the difference in contact area regarding the 5kg and 10kg normal weight. All figures show a rapid increase of pressure from the sides, ending into a more smooth surface in the middle. However, differences can be seen regarding the opposite sides. The front shows a more rapid increase then the back pressure development. This could be caused by the viscoelastic behavior of the rubber. Also, the right side development differs from the left side. This is caused by deviation in the rubber surface. However, these effects are not so clear in the figures with the 771 (soft) compound. Apparently, the softer (771) compound smoothes these effects. Looking at the pressure peaks, these are not evenly distributed. Again the relief of the tread layer could cause different peaks and dips.

5.4 Comparing with summing and averaging

Figure 5.3 shows the results after using both methods on the same data. There is some difference, but figure 5.4 clearly shows what happens when the resolution of the ’Pick and place’ methods gets bigger. The two bottom figures show great resemblance. When the ’Pick and place’ method no longer improves the resolution it actually does the same as the ’Sum and average’ method. However, a slight difference occurs due to fact that not all the same rows are summed and averaged. This is again due to the fact that the ’Pick and place’ method is more accurate and does not always sum and average the same rows as the other method. Also, the ’Pick and place method’ misses some samples that were used in the ’Sum and average’ method. After the measurements it became
Figure 5.1: Random samples (kg is total normal weight) [BAR].
clear that a few samples were not measured properly. This infected the 'Pick and place' method because it could not pick and place well in that specific area. Therefore some samples had to be removed from the end result. Obviously, the other method is not that sensitive because it simply sums all samples and if 250 samples hold 1 or two 2 wrong samples this has almost no effect on the end result.

Figure 5.2: Improved resolution x5, riding from bottom to top [kg is total normal weight].
Figure 5.3: Improved resolution 'Pick and place' vs 'Sum and Average'

Figure 5.4: Improved resolution 'Pick and place' vs 'Sum and Average' (771 with 10kg)
Chapter 6

Conclusions & Recommendations

Because of the need for an improved resolution of the Tekscan data, this report is about the possibility to improve the Tekscan resolution numerically. With a Matlab programm a data processing method was tested. Also the reproducibility was tested and at the end the solution was compared to the more ordinary way of summing and averaging results.

6.1 Conclusions

It is indeed possible to improve resolution. Using the fixed speed and sample rate it is possible to determine the place of every sample within one measurement. This information is used to pick specific rows from multiple samples and placing them together in one new sample. Because it is known were every sample is taken, the rows of different samples are placed successively creating a new sample with an improved resolution. When even more samples are used it is possible to average more results giving a more smooth result. It is however, difficult to fully computerize this process due to noise or incomplete samples. There is always a need for a manual and visual check to rule out unlikely results.

Raw data also needs to be normalized before conclusions can be given about the results. In order to do this there is a need for a calibration factor, because the raw data has no dimension. However, the normal calibration method does not give good results when different compounds are used. By using the total applied force, the surface on which it is applied and the total sum of the data, the results can be normalized into a contact pressure (Bar).

In order to check reproducibility, experiments were done with a single sample wheel. Using different initial conditions, the resulting maximum values of each measurement were compared. To get enough information without losing the overview, the average and standard deviation are used. The relative difference between those two should in theory be zero because the results would every time be the same. The difference therefor gives some information about the deviation between theory and practice. There is a maximum difference of 25% between similar tests. This relative difference is expected to be caused by irregularities in the tread surfaces and a minor bit is expected to be caused by heterogeneous rubber structures. The rubber structure is again influenced by vulcanization and chemicals used to influence material properties.

Furthermore, no tests are done regarding friction or possible shear stresses. Due to the slow and constant motion (0.04 m/s) during measurements, shear stress and friction is assumed to be constant and therefore not causing difference between similar tests. Moreover, these effects will be only of interest when the tread surface irregularities are ruled out.

For further investigation, two compounds were selected. A hard and a soft compound which, within Vredestein, are numbered 716 and 771 respectively. These compounds are vulcanized in a standard mould under a temperature and time specific to each compound. During vulcanization the rubber properties change due to changes on molecular level.
Eventually it can be concluded that, when enough samples are available and there is no need for an improvement in resolution, it is enough to just sum and average all samples. The latter has also the advantage of taking less process time and it is assumed to be no less accurate.

### 6.2 Recommendations

- Having used Matlab to compute a better resolution and using over 250 samples and 6 times more rows that are picked and placed care should be taken with using this method on a everyday basis. One should keep in mind that the 'Pick and place' method just selects succeeding samples and rows. It is not always certain that the data selected is actually the right to use. Moreover the 'Sum and Average' method just sums and averages all data regardless of its exact position.

- To improve the method research could be done to investigate usefulness of the data. Some data or samples may deviate strongly from the rest due to wrong measurements. Because the force and the velocity is known, some could be predicted about results that are expected. Especially using the results of this research the Matlab programm can be extended with a data check.

- To have reasonable results for resolution improvement a normal weight of at least 5kg should be used. Lighter weight results in smaller contact area, sometimes having no more then just one pixel of contact area in length. On top of that 5kg result in a pressure that is more or less equal to pressure loads of every day tyres.

- When there is a need for a great number of tests with the Dr Grosch tyre it is recommended to consider purchasing a different Tekscan sheet. The sheet model 5026 has a 2.4 times higher resolution then the current model (8050). This would improve reliability and save time in post processing, but costs about $6000,- (€4500).

- Vredestein Banden BV has a test machine available that can accurately perform relief scans on tyre surfaces. However, this machines needs to be reset for a small tyre like the one being used for this report. This resetting takes time and is not profitable for just one tyre. But, if more tests are done and if there is a need for more exact conclusions regarding pressure deviations this machine would be useful.

- Tyres consisting of several compounds have yet an unknown effect on the resulting rubber structure. Especially oils and some chemicals tend to diffuse. This causes changes in the end results before, during and after vulcanization. It is therefore recommended to perform more tests. For as long as this is not done care must be taken regarding conclusions about multiple compound tyres. Tyres consisting out of more compounds have yet another problem. During vulcanization the shape of the mould and the high pressure the compound is forced outside the mould and in or over the other compound. Especially a small tread layer, as being used in this report, is unlikely to stay homogeneous. Further tests of this effect are recommended if these tyres are to be used more often. Again care should be taken when making conclusions about these tyres as long as these effects are not fully tested.

- The results at hand together with maybe other results or known theory can also be used to correct irregularities. This in order to give the result a more theoretical outcome. This way it is easier to compare the results with FEM.
Bibliography


Appendix A

Matlab preprocess. Determines contact area and improves resolution by using other Matlab programmes

function preprocess_tekscandata
    % This m-file converts a *.asf file with Tekscan data to a Matlab matrix
    %
    % It is therefor assumed that the data is aangenomen wordt dat de data aangeleverd is in standaard .asf-bestand,
    % met steeds hetzelfde format, bovenaan informatie over de meting en x blokken met meetwaarden, wat overeenkomt met x frames. De informatie bovenaan het bestand kan worden gebruikt om waarden van de griddichtheid, % normaalkracht, sampelrtijd en eventueel naam/maat van de band en % velg te vinden.
    %
    % de data wordt ingelezen met read_txt_tekscan.m (C) Thijs Weegerink 2006 %
    % de data wordt bewerkt tot een matrix TSdata % de bewerking houdt in dat per frame de patch met meetwaarden wordt % gezocht en uitgelijnd %
    % het uitvoeren vereist dat zich in de werkmap van Matlab een aantal % bestanden bevindt dat door read_txt_tekscan ingelezen kan worden, met als % naam: FzXX, waar XX de Fz in Newton is. bijvoorbeeld Fz10, als de test % uitgevoerd is bij een normaalkracht van 10 N %
    % VERTICALE BEWEGINGSRICHTING, VAN ONDER NAAR BOVEN %
    % de uitvoer % -matrix TSdata, de drukverdeling over het contactvlak per meting een % kolom, m-bij-n % -Fz_meting, een vector met de waardes voor Fz waarvoor een meting % uitgevoerd is, 1-bij-n % -x_coordinaat, een vector van het coordinaat langs het contactvlak, % 1-bij-m

    [FileName,PathName,FilterIndex]=uigetfile('*.asf',...
% Open filebrowser and select different tests manually
'kies alle data-bestanden', 'Fz', 'MultiSelect', 'on');

v_tekscan = 0.0409;
% Velocity Tekscansheet with respect to the tire

R = [];
% Initiate R for structure R. Used for data about reliability and reproducibility
% **********************************************************************
% **********************************************************************
% inlezen van het informatiebestand
if FilterIndex==0
  beep
  error('No file choosen')
  return
end

for i=1:numel(FileName)
  % verwerk elk bestand een voor een tot een TSmtrx
  % read_txt_tekscan(strcat(PathName,FileName(i))); als het
  % bronbestand niet in de werkmap van Matlab staat
  [TSmtrx, TKS, TEKSCAN_INFO] = ...% Convert .asf file from Tekscan into Matlab matrix (TSmtrx)
  % [TKS] = check_tks_testparameters(TKS);
% Check TKS structure for missing values and afterwards display TKS
  disp('TSmtrx overgenomen')
  [boundaries,X,Y] = determine_boundaries_tekscandata(TKS,TSmtrx,5);% Filter usable data from TSmtrx
  TSmtrx_improved = improve_resolution_tekscandata(TKS,...% Improve resolution (fourth placed variable is end resolution)
    TSmtrx,boundaries,5,v_tekscan,X);

  str=sprintf('einde berekeningen aan bestand %d van %d',i,...
    length(FileName));
  disp(str)
  for n = 1:size(TSmtrx,1)
    % Fill matrix with peak values
    for m = 1:size(TSmtrx,2)
      TSmtrx_peak(n,m,i)= max(TSmtrx(n,m,:));
    end
  end
  R = setfield (R, ['mean_' num2str(i)],...% Compute mean values per column
    mean(TSmtrx_peak(:,min(X):max(X),i)))
  R = setfield (R, ['std_' num2str(i)],...% Compute standard deviation
std(TSmtx_peak(:,min(X):max(X),i))); 
R = setfield (R, ['reliability_' num2str(i)], ... 
% Standard deviation over Mean 
std(TSmtx_peak(:,min(X):max(X),i))./
mean(TSmtx_peak(:,min(X):max(X),i)*100)); 
save_name = char(FileName(i)); 
% Save data 
save_name = save_name(1:length(char(FileName(i)))-4); 
save(['TekScangegevens_' save_name,'R','TSmtx','TSmtx_improved',... 
'TSmtx_peak','boundaries','TKS','TEKSCAN_INFO','X','Y'); 
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% 
%%% If name already exists, file is not saved %%% 
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%% 
disp(sprintf('Saving ', char(FileName(i)))) 
end 
warning off all 
% Because of large number of cells in matrix is 0, many warnings will appear 
TSmtx_compare=[]; 
% Initiate matrix for data about comparison 
for i = 1:size(TSmtx_peak,1) 
% Calculate difference in peak values of two measurements 
k=1; 
for j = min(X):max(X) 
TSmtx_compare(i,k)= TSmtx_peak(i,j,1)/TSmtx_peak(i,j,2); 
k=k+1; 
end 
end 
R = setfield (R, ['mean_compare'], mean(TSmtx_compare)); 
% Compute mean values per column for comparison 
R = setfield (R, ['std_compare'], std(TSmtx_compare)); 
% Compute standard deviation values per column for comparison 
R = setfield (R, ['reliability_compare'], std(TSmtx_compare)*100./... 
% Standard deviation over mean values per column for comparison 
mean(TSmtx_compare)); 
save(['TekScanreliabilitycheck'], 'R','TSmtx','TSmtx_improved',... 
% Save file with data about reliability 
'TSmtx_peak','boundaries','TKS','TEKSCAN_INFO','X','Y'); 
figure(1) 
% Plot difference in peak values 
imagesc(TSmtx_compare) 
colorbar
Appendix B

Determine boundaries contact surface area

% function [boundaries,X,Y] = determine_boundaries_tekscandata(TKS,TSmtrx,LINES_NOT_TO_TAKE)
% Determine first boundaries by hand and find the others with help of

% This function promts one frame with 'spy' and asks for picking two points
% that set a square for the data used. This can be done roughly and is just
% to easily ignore a large part of the matrix which ofcourse can hold noise.
%
% The rest of the frames are then scanned for boundaries that represent
% only that part of the matrix that holds the data
%

m=round(TKS.FRAMES/2);
% Compute centre frame
figure(1)
spy(TSmtrx(:,:,m));
% Show plot with datapoints from centre frame
title('Pick roughly two points of a square that determine the boundaries')
% Use title as question
grid

[X,Y] = ginput(2);
% Ask user to pick two reference point for reference
X = round(X);
% Round X coordinates
Y = round(Y);
% Round Y coordinates

if LINES_NOT_TO_TAKE <= 1
% Limits the variable that is needed for a good data file
    LINES_NOT_TO_TAKE = 2;
    disp('For computational reasons the variable LINES_NOT_TO_TAKE is set to 2')
end

X = [56 74];
iii=1;
% Set first row for matrix 'boundaries'
colormap('jet')
for i = 1:TKS.FRAMES
% For every frame find the boundaries for usable data
[p,q]=find(TSmtrx(:,min(X):max(X),i));
% Find non zero elements of TSmtrx within column of min(X)-max(X)
% This min-max is determined by user and because the wheel runs straight
% during measurement every sample has almost the same columns

    if min(p)>(0+LINES_NOT_TO_TAKE) & max(p)<=(TKS.COLS-LINES_NOT_TO_TAKE)
% Check whether the data is usable. In other words, does the tyre already
% its full contact area on the Tekscan sheet and not half in front or half after
        if ~isempty(p)
% Find non zero elements and determine its boundaries.
            boundaries(iii,:,1)=[min(p)-1 min(q)-1 max(p)+1 max(q)+1 ...
                            max(p)-min(p) max(q)-min(q) i];
            iii=iii+1;
% Go to next row within 'boundaries'
            figure(1)
% Plot data. When plotted one can roughly see if results are correct
            title(num2str(i))
            pause(5/TKS.FRAMES)
            imagesc(TSmtrx((min(p)-1):(max(p)+1),...
% Set boundaries
                (min(X)+min(q)-2):(min(X)+max(q)),i))
            grid
        end
    end
end

% 1 min(p): first row with non zero element
% 2 min(q): most left column with non zero element
% 3 max(p): last row with non zero element
% 4 max(q): most right row with non zero element
% 5 max(p)-min(p): height of non zero area
% 6 max(q)-min(q): width of non zero area
% 7 frame number
Appendix C

Improve resolution

% function [TSmtrx_improved] = improve_resolution_tekscandata(TKS,TSmtrx,boundaries,WANTED_RESOLUTION,v_tekscan,X)
% Use tekscan data to numerical improve resolution using resolution input.
%
% This function uses the given speed and sampletime to numerically improve
% the resolution of the tekscan measurements.
% In order to achieve this different frames are combined into one new frame
% with a higher order resolution. This can be done because not all (or
% none) of the frames measure the same elements of the rubber. Every time a
% new piece of rubber is measured that lies just in front or at the rear of
% the previous element.
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%%WARNING%%%%%%%%%%WARNING%%%%%%%%%%WARNING%%%%%%%%%%WARNING%%%%%%%%%
% %
% This function is sensitiv to noise and other wrong data
% %
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% In order to improve the reliability (not accuracy) it is chosen to
% average some points. This way information presented does not rely on one
% but on more measurements. However it is still unsure whether these
% averaged points lie close to eachother.

V_TEKSCAN = v_tekscan;
% Speed tekscan
V_PRESSURE_POINT = TKS.ROW_SPACING/V_TEKSCAN;
% Speed of a pressure point
POSSIBLE_RESOLUTION = V_TEKSCAN/(TKS.SAMPLETIME-V_PRESSURE_POINT);
% Smallest resolution possible
POINTS_AVERAGED = round(POSSIBLE_RESOLUTION/WANTED_RESOLUTION);
% Number of points that needs to be averaged
temp = [];

if POINTS_AVERAGED < 1
    POINTS_AVERAGED = 1;
end
FIRST_FRAME = boundaries(1,7);
% Look for first frame having a good measurement
LAST_FRAME = boundaries(size(boundaries,1),7);
i=1;

while boundaries(size(boundaries,1)-i+1,5) == 0
LAST_FRAME = boundaries(size(boundaries,1)-i,7);
% Look for last frame having a good measurement
i=i+1;
end

TSmtrx_improved = [];
% Preallocating memory for improved matrix
TSmtrx_temporary = [];
% Preallocating memory for matrix only used in this function
check = [];

%**************************************************************************
%**************************************************************************

n=1;
% Set first frame for temporary matrix

for framenr = FIRST_FRAME:round(POSSIBLE_RESOLUTION):LAST_FRAME-round(POSSIBLE_RESOLUTION)
% for each reference frame

    FIRST_ROW = boundaries(framenr+1-FIRST_FRAME,1);
% Look for first row in reference frame
    LAST_ROW = boundaries(framenr+1-FIRST_FRAME,3);
% Look for last row in reference frame

    ii = 1;
    if FIRST_ROW < boundaries(framenr+2-FIRST_FRAME,1)
    % Determine wether measurement is done forward or backward
    temp = i;
    end

    % ii indicating row in temporary matrix
    for k = FIRST_ROW:1:LAST_ROW
    % for each row of reference frame

        iii=0;
        % iii indicating the rows that lie between the rows of the reference frame
        p = round(POSSIBLE_RESOLUTION)+1;
        for i = framenr:framrn+round(POSSIBLE_RESOLUTION)-1
        % for each frame in the original TSmtrx pick a row

            if isempty(temp)
            if k-iii > 0
            % Avoid error if index < 1
            TSmtrx_temporary(ii,:,n) = TSmtrx(k-iii,...
                min(X):max(X),i);
            end

        end

    end

end

%**************************************************************************
%**************************************************************************
% Align rows of original matrix into temporary matrix
check = [check;[k-iii,ii,i,n]];
iii = iii+1;
% Set next row for original matrix
ii = ii+1;
% Set next row for temporary matrix
end
else
if k+iii < TKS.COLS
% Avoid error if index < 1
TSmtrx_temporary(ii+p,:,n) = TSmtrx(k+iii,...
  min(X):max(X),i);
% Align rows of original matrix into temporary matrix
check = [check;[k+iii,ii,i,n]];
iii = iii+1;
% Set next row for original matrix
ii = ii+1;
% Set next row for temporary matrix
end
end
% end if
p=p-2;
end
% end for
end
% end for
n=n+1;
% Set new frame for temporary matrix
end
% end for

k = 1;
% Set first row for improved matrix
for i = 1:POINTS_AVERAGED:size(TSmtrx_temporary,1)-1
% Take all first point that should be averaged
  if POINTS_AVERAGED+i <= size(TSmtrx_temporary,1)
% Avoid error if index < 1
    TSmtrx_improved(k,:,:) = ... 
% Average rows of temporary matrix and place mean in improved matrix
    mean(TSmtrx_temporary(i:i+POINTS_AVERAGED,:,:));
    k=k+1;
% Set next row for imporved matrix
  end
end
end

close all
for i = 1:size(TSmtrx_improved,3)
    % Show figures with new matrix
    figure(1)
    contour(TSmtrx_improved(:,:,i))
    pause(5/size(TSmtrx_improved,3))
end
Appendix D

End process. Normalization and sum and average all improved samples

% This file is run separately from the other functions. It computes the average of the new matrices made by the file 'improve_resolution_tekscandata.m'. This can not be done automatically because some new matrices are 'fake' because of some wrong sample in the raw data. These fake matrices need to be expelled from this computation.

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%WARNING%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% This file is not mentioned to improve results just by leaving out unexpected data. However, during research it became clear that the Tekschan sheet sometimes has incomplete samples. This can be seen when looked at every sample separately. Some few sample may deviate strongly regarding the contact area (in size) from the others. This causes the improvement 'improve_resolution_tekscandata.m' file to give strange, unlikely results that also strongly deviate from the rest of the results.
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

USED_WEIGHT = 50; % In Newton [N]
% Weight used during measurement
RESOLUTION = 5;
% Resolution

new_TSmtrx = TSmtrx_improved(:,:,1:5,7:11);
% Make new matrix. Expell matrices that hold twisted data
all = sum(new_TSmtrx,3);
% Sum all matrices
averaged = all/size(new_TSmtrx,3);
% Average summed matrices

new_TSmtrx = averaged;

force = sum(sum(new_TSmtrx));
% Compute total not normalized force.
force = force/USED_WEIGHT;
% Normalize force
new_TSmtrx = new_TSmtrx./force./(1.524e-3/RESOLUTION*1.524e-3)./1e5;
% Compute pressure load for every cell in new matrix

figure(1);contourf(new_TSmtrx);colorbar
% Plot result
Appendix E

Convert ’.asf’ file into Matlab matrix

% function [TSmtrx,TKS,TEKSCAN_INFO] = read_txt_tekscan(filename)
% filename

% Script to convert TekScan ASCII data to matlab data.
% The configuration of the TekScan software should be:
%
% Number of Frames: 250 [-]
% Seconds per Frame: 0.04 [s]
%
% HOW TO USE
%
% Enter: read_txt_tekscan(filename)
% to start the conversion.
%
% INPUT
%
% An ASCII file containing data from a TekScan movie
%
% OUTPUT
%
% M_movie, containing the footprint in a 3D matrix [m,n,p]
% m = length of the footprint
% n = width of the footprint
% p = frame number (time step)
% 1 output unit = 0.1 [Bar]

%------------------- Version 15-09-2006, Thijs Weegerink ------------------
%------------------- Created by HVB @ 08-09-2006 ------------------

fid = fopen(char(filename));
% Open filename for read access

tline = 'a';
% Tline may not be empty at the beginning, so the value 'a' is arbitrary
p = 1;
% Start at frame 1
movie = zeros([176,192,250]);
% Preallocating memory for variable
str = sprintf('opent %s', char(filename));
TEKSCAN_INFO = [];
% Cell array of strings for information about test

disp(str)

% ***********************************************************************
% ***********************************************************************
while isempty(tline) | ( ~isempty(tline) & ~strcmp(tline(1),'@') )
% When a '@' is read, the end of the file is reached

if isempty(tline)
    tline = fgetl(fid);
    % Line with text: Frame (number), go to next line
    tline = fgetl(fid);
    % Read first line of data
    m = 1;
    while ~isempty(findstr(tline,',')) % vervangen door ,
    % As long as there is data in tline
        tline = strrep(tline,',',' ');
        % Change the separation comma into an empty space.
        movie(m,:,p) = sscanf(tline,'%f',[1,192]);
        m = m + 1;
        % Next m (is next line of sensels)
        tline = fgetl(fid);
    % Read next line of data
    end
end
% End while
p = p + 1;
% Next p (is next frame (timestep))
else
    tline = fgetl(fid);
    % Read empty line
    TEKSCAN_INFO = char(TEKSCAN_INFO,tline);
    % Store test infomartion in info matrix
    parameters_temp = sscanf(tline,'%s %*f *s');
    % Temporary parameter storage
    switch parameters_temp
    case ('ROWS')
        TKS.ROWS = sscanf(tline,'%*s %f');
        % Tekscan rows
    case ('COLS')
        TKS.COLS = sscanf(tline,'%*s %f');
        % Tekscan columns
    case ('ROW SPACING')
        TKS.ROW_SPACING = sscanf(tline,'%*s %f')/1000;
        % Space between rows [m]
    case ('COL SPACING')
        TKS.COL_SPACING = sscanf(tline,'%*s %f')/1000;
        % Space between columns [m]
case ('SENSEL_AREA')
    TKS.SENSEL_AREA = sscanf(tline,'%*s %f')/1000^2;
    % Sense area [m^2]
    if sscanf(tline,'%*s %*f %s') == 'inš'
        % Test for inches or mm and change units
        TKS.SENSEL_AREA = TKS.SENSEL_AREA*25.4^2;
        TKS.ROW_SPACING = TKS.ROW_SPACING*25.4;
        TKS.COL_SPACING = TKS.COL_SPACING*25.4;
    end
    % end for
    TKS.SAMPLETIME = sscanf(tline,'%*s %f');
    % Seconds per frame
    TKS.TIREWIDTH = sscanf(tline,'%*s %f');
    % Tirewidth as in normal tiredimensions
    TKS.TIREHEIGHT = sscanf(tline,'%*s %*f %*c %f');
    % Tireheight as in normal tiredimensions. In precentage (as usual)
    TKS.TIRERADIUS = sscanf(tline,'%*s %*f %*c %*f %*s %f');
    % Tirketiradius as in normal tiredimensions
    TKS.TRESHOLD = sscanf(tline,'%*s %f');
    % Noise treshold used by Tekscan
    TKS.LOAD = sscanf(tline,'%*s %f');
    % Load [kg]
    TKS.FFRAME = sscanf(tline,'%*s %f');
    % First frame (in principal always 1)
    TKS.FRAMES = sscanf(tline,'%*s %f');
    % Last frame (also refered to as number of frames)
    otherwise
        % Just continue when no case is true
    end
    % End switch
end
% End if
% End while
fclose(fid);
% Close file
TSmtrx = permute(movie,[2,1,3]);
% Reshape matrix
disp('TSmtrx gemaakt')
% TSmtrx = uint8(floor(TSmtrx * 10));
% Convert to uint8 for memory reasons, Output: 1 [unit] = 0.1 [Bar]
% End function

%-----------------------------------End of script-----------------------------------