How to build a rein tension meter

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Hur man bygger en tygeltrycksmätare

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Abstract

A large part of the interactions between horse and rider during horseback riding takes place through the reins and the bit and devices for measuring the tension on the reins, rein tension meters, has fairly recently been developed. To safeguard the welfare of the ridden horse riders need to be aware of the rein tension they apply and actively work to decrease it. Furthermore, there is a need to develop the study of rein tension through new techniques and refined analysis procedures. A good-quality rein tension meter should be small in size, sensitive, durable and as accurate for light rein tension as for strong forces. Rein tension meters used in research on horse and rider interaction commonly depend on strain gauge technique for generating rein tension data. Strain gauges are electrical resistances and when subjected to tension or compression the resistance change. By connecting the strain gauges in a Wheatstone bridge circuit the sensitivity of the measure is increased and the circuit is compensated for temperature changes.

The aim of this project was to create a durable rein tension meter at a low cost that would be as accurate for high loads as for small changes of tension. The rein tension meter was made from bent stainless spring steel, strain gauges, a custom made amplifier and electric cable. Three different sizes of steel, 140*40*1 mm (large), 110*35*1 mm (medium) and 90*30*1.5 mm (small) and two different types of strain gauges, pairs of parallel strain gauges and pairs of perpendicular strain gauges, were tested. Power and logging of data was supplied through an Inertial Measurement Unit. The rein tension meters were calibrated by lifting known weights and were tested at local riding schools as well as with privately owned horses. The maximum force the steel could withstand was calculated and the stability of the output voltage to the same weight was tested. A polynomial regression calculation was used to convert the voltage output received from the ridden tests into rein tension in kilograms.

The results show that the pairs of parallel strain gauges were most appropriate to use, the small size meter was most durable due to being thickest and the small size meter also had the most appropriate measuring range of 285 g to >30 kg. Repeated calibrations of the small rein tension meter with the same weight yielded similar values. The mean of the mean rein tension received from the school horses were 1.2 kg for the left rein and 1.11 kg for the right rein. The maximum rein tension registered was with a horse that was difficult for the rider to control and would run off frequently during the ride and its highest rein tension peak reached 31.58 kg.

In conclusion, the rein tension meters created were found to be both durable and accurate and well suited for rein tension measurements and the small size rein tension meter with a measuring range of >30 kg is likely enough to register rein tension in most horses and riders. This rein tension meter can also potentially synchronize the rein tension data with the stride cycle. To safeguard the welfare of the horse, training techniques and rider performance need to be measured and evaluated and a tool like this rein tension meter makes it possible to monitor, at least in part, the interactions taking place between horse and rider.

Sammanfattning

En stor del av kommunikationen mellan häst och ryttare sker via tyglarna och bettet och relativt nyligen har instrument som kan mäta kraften i tyglarna under ridning börjat användas inom forskningen, så kallade tygeltrycksmätare. Som ryttare bör man vara medveten om det tygeltryck man använder under ridning och för att säkerställa hästens välmående bör man aktivt sträva efter att minska tygeltrycket. Vidare bör forskningen på tygelkrafter under ridning utvecklas genom ny teknik och förbättrade analysmetoder. En tygeltrycksmätare av god kvalité bör vara liten, känslig, hållbar och lika exakt i sina mätvärden för små som stora krafter. De tygeltrycksmätare som tidigare har använts inom forskning på ridning bygger på trådtöjningsgivare. När en trådtöjningsgivare utsätts för töjning eller kompression ändras dess elektriska motstånd och genom att koppla ihop trådtöjningsgivarna i en s.k. Wheatstone brygga ökar mätningens känslighet och den elektriska kretsen kan kompensera för temperaturskillnader utan att det påverkar de elektriska värdena.

Syftet med detta projekt var att skapa en hållbar tygeltrycksmätare till en låg kostnad med exakta mätvärden för såväl små som stora tygelkrafter. Som material användes böjt rostfritt bandstål, trådtöjningsgivare, en förstärkare och elektrisk kabel. Tre olika storlekar på stål, 140*40*1 mm, 110*35*1 mm och 90*30*1,5 mm, och två olika typer av trådtöjningsgivare (parallella par och vinkelräta par) testades. En Inertial Measurement Unit gav tygelmätaren ström och lagrade tygeltrycksdata. Tygeltrycksmätarna kalibrerades genom att lyfta kända vikter och testades även under ridning. Den maximala kraften stålet kunde tåla beräknades och stabiliteten i voltutslagen testades. Genom en beräkning av polynomförhållandet mellan kända vikter och voltutslag under kalibrering kunde tygeltrycksdata från ridningen omvandlas till kilogram tygeltryck.

Resultaten visade att par av parallella trådtöjningsgivare är mest lämpliga att använda, att den minsta storleken på stål var mest hållbar, då den också var tjockast, och att denna minsta mätare även hade det mest lämpliga mätområdet på 285 g till >30 kg. Vidare gav upprepad mätning av samma vikt under kalibreringen liknande värden. Medeltygeltrycket var 1,2 kg för vänster tygel och 1,11 kg för höger tygel då ridskolehästar reds med mätarna. Det maximala tygeltrycket som uppmättes under ridningen var med en häst som var svårkontrollerad och drog iväg med ryttaren och tygeltrycket nådde då som högsta 31,58 kg.

Sammanfattningsvis blev tygeltrycksmätarna både hållbara och exakta i sina mätvärden och fungerade väl för tygeltrycksmätningar på häst. Den minsta storleken på mätare med ett mätområde på >30 kg är troligtvis nog för att registrera tygeltryck hos de flesta ekipage. Denna tygelmätare kan troligtvis även användas för att synkronisera tygeltrycksdata med stegcykeln. För att säkerställa hästens välfärd under ridning bör träningsmetoder och ryttarens interaktion med hästen mätas och utvärderas och ett verktyg som denna tygeltrycksmätare gör det möjligt att, i alla fall delvis, följa samspelet mellan häst och ryttare.

Introduction

In horseback riding the rider uses the hands on the reins, attached to a bit in the horse's mouth, to communicate speed, direction and degree of self-carriage to the horse (Manfredi et al., 2010). Applying tension on the reins is thus a large part of the horse-rider interaction and what is strived for are correct behavioural responses to light rein tension signals. Devices for measuring rein tension have fairly recently been developed. There are a limited number of studies on few horses and riders, of which most are pilot studies (Clayton et al., 2003; Clayton et al 2005; Warren-Smith et al., 2007; Heleski et al., 2009; Kuhnke et al., 2010; Egenvall et al., 2012; Eisersiö et al. accepted). A few examples of what can be learned from these studies are that the rider's perception of rein tension can differ immensely from reality (Clayton et al., 2003), that riders have diverse perception of what is a 'medium contact' with the horse's mouth (Randle, 2010) and that both horses and riders contribute to unevenness in rein tension of the left and right rein (Kuhnke et al., 2010).

The rider's timing and consistency in giving rein signals can likely be elucidated by studying rein tension data, yet such studies are scarce. Also, correlating rein tension data with the kinematics of horse and rider yields additional information about cause-effect factors when studying the horse-rider interaction. In Warren-Smith et al. (2007) it is stated that riders need to be aware of the rein tension they apply and actively work to decrease it to safeguard horse welfare. This statement is understandable considering that oral soft tissue ulcers are more common in horses currently being ridden with a bit in their mouth compared to horses not currently ridden (Tell et al., 2008) and evasive mouth behaviours were more often seen when rein tension was applied compared to no rein tension (Manfredi et al., 2010). Further it has been observed that young, inexperienced horses find the cost of increased pressure in the mouth larger than the benefit of a food reward (Christensen et al., 2011). As rein tension involves complications like these, it has been suggested in Warren-Smith et al. (2007) that rein tension should be monitored and measured in equestrian competitions as an objective assessment of the horse-rider performance. It is thus important to develop the study of rein tension through new techniques and refined analysis procedures.

Rein tension meters for research

Rein tension meters used in research on horse and rider interaction commonly depend on strain gauge technique for generating rein tension data. The Signal Scribe rein tension meter (100 Hz, Crafted Technology, Australia), a measuring device relying on strain gauge technique, has been used in Warren-Smith et al. (2007), Kuhnke et al. (2010), Christensen et al. (2011) and Egenvall et al. (2012), to mention a few studies. Whereas in Clayton et al. (2003), Heleski et al. (2009) and Manfredi et al. (2010), a strain gauge transducer from Transducer Technologies (240 Hz, Temecula, USA) was used.

Strain gauges are electrical conductors with electric resistance that consist of a metallic foil pattern supported by an insulating flexible backing (figure 1; Hoffman, 2012). Tension or compression of the foil results in a change of resistance. In other words, if there is movement in the installation area underneath the strain gauge, the resistance in the strain gauge will change, as will the electrical output in the circuit (Hoffmann, 2012). By calibrating the measuring device with known weights the electrical output can be transformed into the applied tension. Since strain gauges are both sensitive and durable in their design they are well suited for rein tension measurements.

Even though strain gauge technique is a well-established measuring technique with many application areas, other variables also affect the correctness and function of a measuring device. Several problems with the Signal Scribe rein tension meter has been reported; after a high load has been applied, the meter does not always return to the same zero point (Rein tension meter, Help Manual, V 1.0; Christensen et al., 2011), the left rein has been reported to be non-linear at higher values (Christensen et al. 2011), and the durability of the meter is inadequate for usage among horses (personal observation, 2010). Further, Signal Scribe has an upper measuring threshold of 10 kg (98N) which is easily surpassed (personal observation, 2011). The strain gauge transducers from Transducer Technologies has a larger measuring range being able to withstand tension up to 68 kg (667N) and yielding accurate rein tension data up to 45 kg (445N). Previous studies have reported maximum rein tension ranging from 3 to 10 kg (Clayton et al. 2005; Warren-Smith et al., 2007; Kuhnke et al. 2010).

The properties of a high-quality rein tension meter

A well-functioning rein tension meter needs to be small in size to not interfere with the normal movement and function of the reins (Clayton et al., 2003). It also needs to be sensitive and accurate over a wide range of loads as well as robust to withstand being operated among horses (Clayton et al., 2003). Further, electrical meters need to be provided with power and rein tension data need to be transmitted and stored appropriately during the ride. Changes in temperature can easily change the properties of electrical components, resulting in changes of resistance and consequently electrical output. By installing four strain gauges in a bridge circuit, i.e. the Wheatstone bridge (Hoffmann, 2012), so that two strain gauges are tensed and two are compressed when subjected to strain, any temperature changes are compensated for and the accuracy of the measurement is increased (Hoffmann, 2013). When the measuring device is unloaded the input voltage is equal to the output voltage in the Wheatstone bridge circuit. As tension is applied to the device, the resistance of the strain gauges change and so does the output voltage signal.

Aim

To meet the increasing standards of research in horse-rider interaction, this project aimed at creating a rein tension meter that would withstand all kinds of situations that may appear during horseback riding, like sudden and repeated high loads, low and vibrating rein tension, wet and moist weather, dust and dirt from the horses and riding arenas as well as the different temperatures of summer and winter. Taking account of these parameters, the rein tension meter also has to be accurate, have a large measuring range, be durable in design, and have excellent recording management, all at a fairly low cost.

Material and methods

Material

A complete rein tension meter consists of two tension meters, one for each rein. To construct the meters a design with variation in some components was employed. Each tension meter was made from a piece of stainless spring steel (SS 1770-04, tempered), four strain gauges (figure 1) (parallel pairs of strain gauges – DY41-3/350 or perpendicular pairs – XY31-3/350, HBM, Sweden), a custom made amplifier (ROLAB) and electric cable. Three different sizes of steel were tested. First the sizes 140*40*1 mm (large) and 110*35*1 mm (medium) were tested with parallel pairs of strain gauges on the left tension meter and perpendicular pairs on the right tension meter. Then spring steel of 90*30*1.5 mm (small) in size was tested with parallel pairs of strain gauges on both left and right tension meter. The meters were connected to an Inertial Measurement Unit (IMU, x-io Technologies Limited, UK) for power supply and rein tension data were collected on a micro SD card in the IMU (see below).

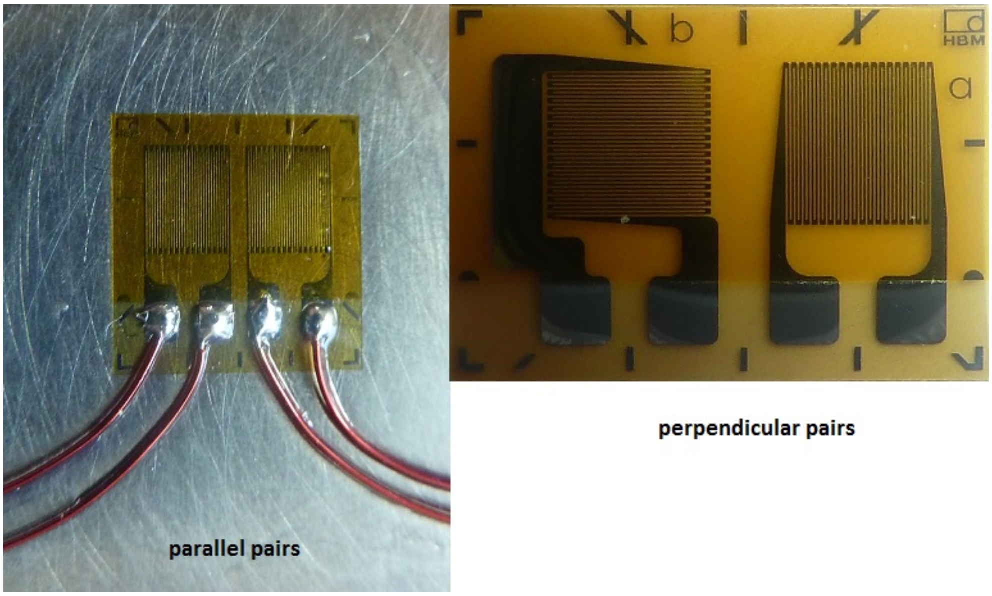


Figure 1. The metallic foil pattern of the strain gauges is placed parallel to each other in the pair of strain gauges to the left and perpendicular to each other in the pair of strain gauges to the right.

Overall design

The steel was punctured with five holes (4 mm in diameter), one in each corner and one on the long side 12 mm from one of the corner holes (figure 3). The steel was then bent so that the height of the arch was 22 mm for the large meter, 18 mm for the medium and 12 mm for the small size meter. One pair of strain gauges was attached, in the middle of the bend, on either side of the steel. The metallic foil patterns of the parallel pairs of strain gauges were placed parallel to the long side of the steel. The foil pattern of the perpendicular pairs were placed so that one of the strain gauges was parallel to the long side and the other one was perpendicular. The strain gauges were interconnected in a Wheatstone bridge circuit (figure 3) through the use of soldering terminals and a custom made amplifier was inserted between the Wheatstone bridge circuit and the IMU. Fastening the rein tension meter to the rein was done by running the rein over the bend and pinching it between the steel and a metal piece of matching width (40/35/30*12*1 mm). The rein was tightly pinned at one end and loosely attached at the other end using screws and lock nuts. Pulling on the reins thus slightly straightened the steel bend causing tension and compression of the strain gauges and consequently detectable changes of output voltage that could be logged in the IMU.

IMU

The IMU holds a gyroscope, an accelerometer and a magnetometer recording data at frequencies up to 512 Hz. It also holds an 8-channel auxiliary port, a real-time clock/calendar and a card holder for a micro SD card. The software accompanying the IMU, the x-IMU GUI (Graphical User Interface, www.x-io.co.uk/products/x-imu), is used to configure the settings, to view sensor data in real-time and to export data to, for example, MATLAB (MathWorks Inc.) and Excel (Microsoft Inc.). The size and weight of the IMU is 57*38*21 mm and 100 g, including plastic housing and battery. The auxiliary port was set to analogue input and used for data transmission. It has 8 I/O (Input/Output) channels, a 12-bit resolution and 0 to 3.3 V measuring range. The IMU was positioned on the horse's forehead, right below the browband, with the X-axis upwards/downwards (aligned with the bridge of the nose), the Y-axis left/right and the Z-axis forwards/backwards. Besides storing data and supplying the rein tension meter with power, the accelerometer (triple axis, 12-bit) in the IMU registered the accelerations of the horse's head during movement. Preliminary observations indicate that the linear accelerations of the horse's head movement can be used for gait identification and studying the variation of rein tension over the stride cycle (figure 2).

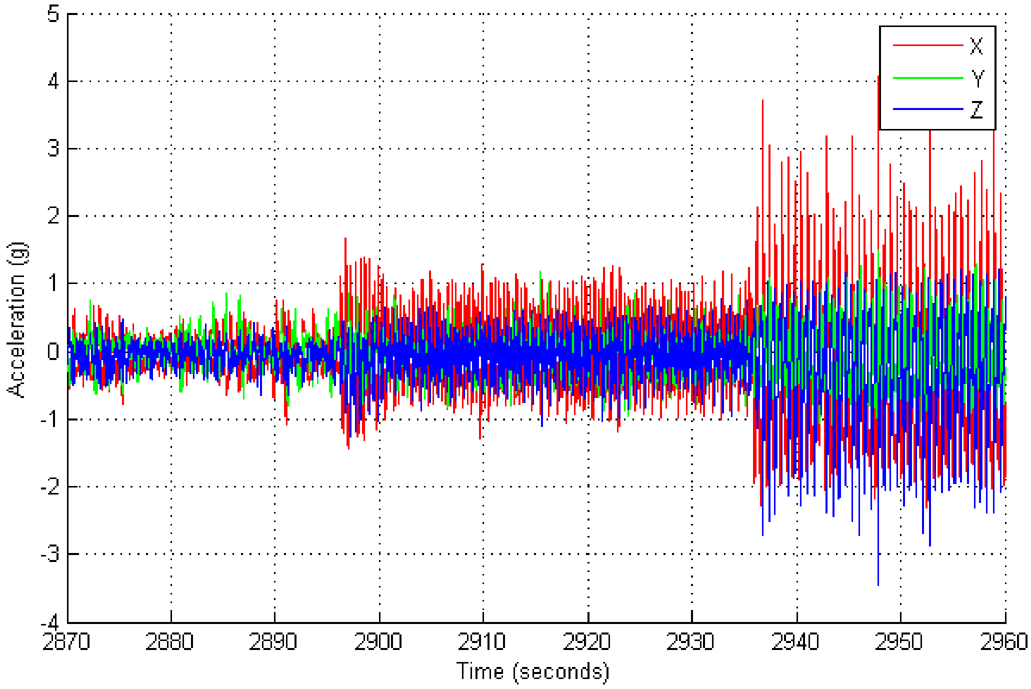
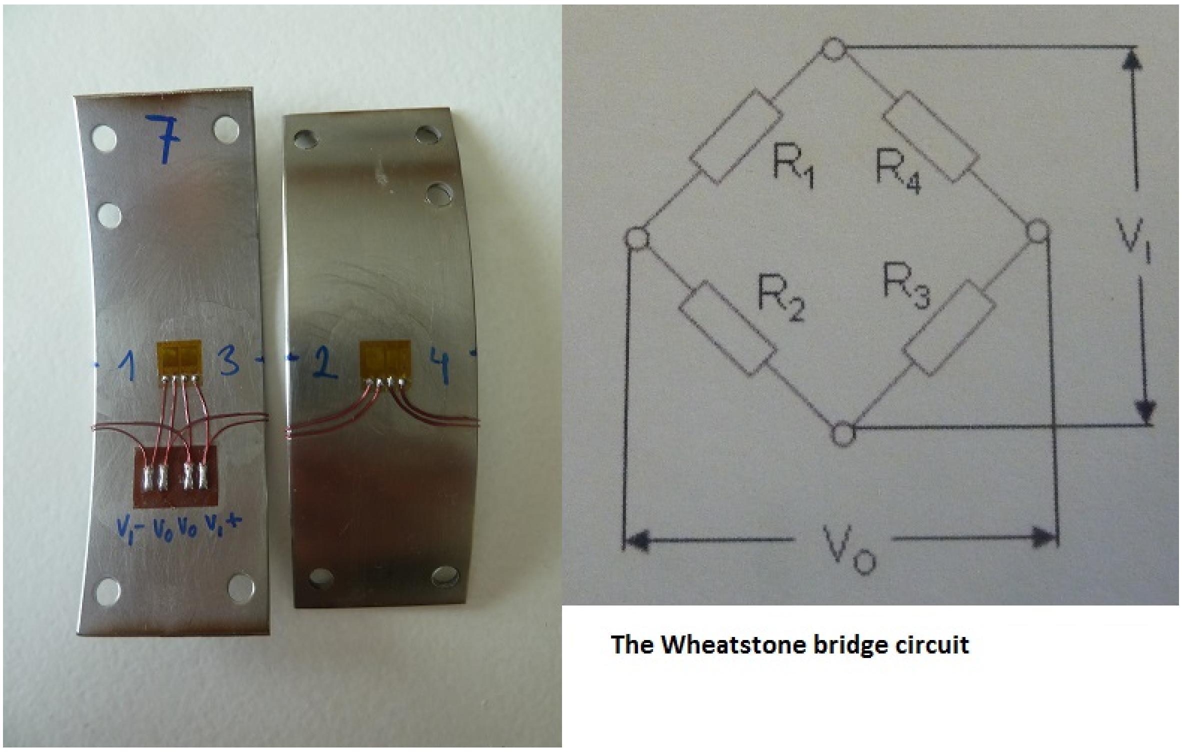


Figure 2. Example of the linear acceleration of the horse's head in the X-, Y- and Z-axis in walk (seconds 2870-2895), trot (seconds 2895-2935) and canter (seconds 2935-2960) during 1.5 minutes of data collection.

Method for building the tension meters

Both strain gauges and solder terminals were attached to the steel using quick acting adhesives (Cyanoacrylate, Z70). Before the installation of the strain gauges and the solder terminals the measuring point was thoroughly prepared. The steel was carefully cleaned to remove impurities and foreign materials using a sponge and soap water. The application area was then degreased using acetone (100% chemically clean). A larger area was first cleaned and then cleaning continued inside that area. This was to avoid impurities being rubbed into the measuring point from the edges. To ensure superb attachment of components, the installation area was lightly roughened using a medium-coarse emery cloth. The uneven surface gave the adhesive a larger attachment area (Hoffmann, 1996). After a final cleaning with acetone, the measuring point was ready for installation of the strain gauges and solder terminals. Adhesive tape was used to ensure straight placement of the strain gauges onto the steel. The strain gauges were covered with tape and positioned on the steel, creating a hinge-like connection holding the strain gauge in place while one drop of cyanoacrylate was applied. The strain gauges were then folded down, a piece of Teflon foil was placed over it, and then, using the thumb, the strain gauges were firmly pressed against the surface for two minutes. The same procedure was applied when installing the solder terminals. The solder terminals were attached on the concave side of the metal piece beside the strain gauges. The electrical elements were joined together through soldering. Copper wire (0.04 mm) was used to interconnect the strain gauges with the solder terminals. A soldering tip of 0.4 mm (conic shape) in size and solder with rosin core (1.0 mm) was used. The setup of the strain gauges, solder terminals and the Wheatstone bridge circuit can be seen in figure 3. To protect the measuring points from dirt, damage, dust and moist two thin layers of Polyurethane coating was applied and allowed to cure for 96 h in room temperature.



The Wheatstone bridge circuit

Figure 3. The positions and connections of the parallel strain gauges and solder terminals on the small rein tension meter to the left and a drawing of the Wheatstone bridge circuit to the right. Vi is for voltage input and Vo for voltage output. R_1 to R_4 represent the strain gauges 1 to 4.

The amplifier was used to magnify the voltage changes, making the signal detectable for the IMU. The amplifier was attached directly on top of the strain gauges on the concave side using silicone and its connector wires were soldered to the solder terminals and to an electric cable attached to the IMU. The amplifier was equipped with an offset knob for adjusting the zero level and a LED-light for indicating current flow. Different levels of amplification were tested: 279, 329, 377, 427, 485, 828, 1342 and 1892 times amplified signal. The electric cable from each rein tension meter was 1 m, long enough to fit a full size horse, and secured with a cable tie to the extra hole in the steel. The cable wires from the left and right tension meter were soldered onto the same 2*6 connector pin which fit into the auxiliary port of the IMU. The wires were connected to the common ground, the 3.3 V power output and the I/O channels AX6 (left rein) and AX7 (right rein). The connection between the cable wires and the connector pin was strengthened by placing a sturdy piece of shrink tubing over it and duct tape was used to keep the connector pin secured in the auxiliary port during data collection. Attaching the IMU to the horse's head was done by using a Velcro browband. The tension meters were attached as close to the bit as the buckles on the reins would permit. The cables from the tension meters were running forwards along the reins, beside the bit, upwards along the side pieces of the bridle, behind the horse's ears and down to the horse's forehead where the IMU was located (figure 4). The cables were attached to the reins, side pieces and poll pieces using Velcro. To thoroughly protect the rein tension meters, the larger part of each tension meter received a layer of covering tape (ABM75) and on top of that adhesive tape. The offset knob and LED-light on the amplifier was solely covered with transparent adhesive tape that could be removed at convenience. Figure 5 shows the fully equipped small rein tension meter.

Figure 4. The small rein tension meter attached to a horse.

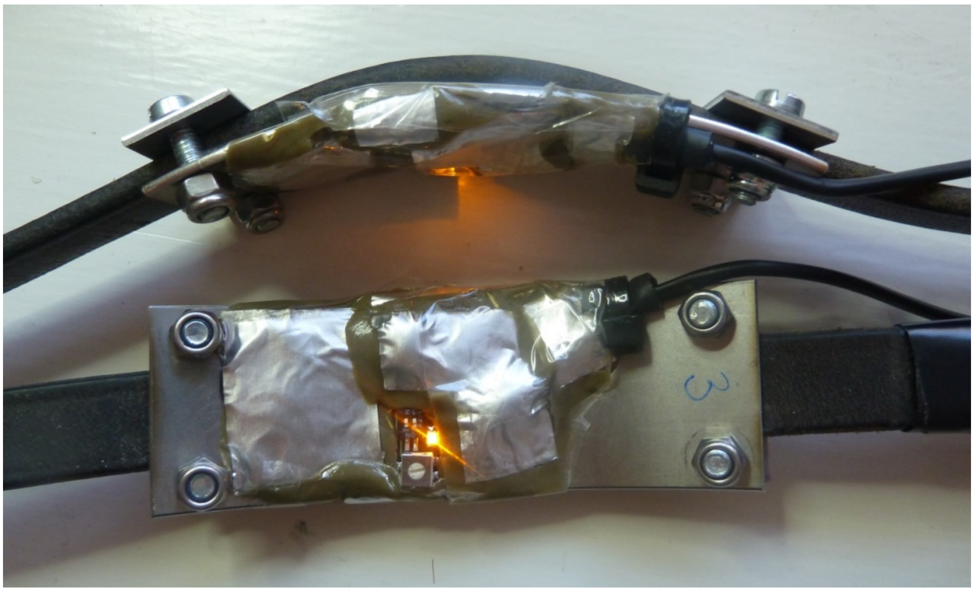


Figure 5. The small rein tension meter covered with covering tape. The offset knob and the LED light can be seen in the middle of the meter.

Stainless strip steel SS 1770-04

After initial field testing of the large and medium rein tension meter it was decided to adjust the size of the steel. Calculations of the durability of the steel were made and analysing the results it was decided to create the small rein tension meter, 90*30*1.5 mm.

Tempered/hardened stainless spring steel strip SS 1770-04 of 0,1-3,5 mm in thickness has a yield point between 1150-1700 N/mm^{2,} depending on the thickness of the material, were it start to deform plastically. Prior to this point the steel only deforms elastically and returns to its original shape when the force applied is removed. The equation for tension (σ) is the force (F) divided by the area (A) and thus the unit for tension is N/mm^2. For a spring steel strip of 1-1.5 mm in thickness the yield point would be about 1350 N/mm^2. To make sure this limit is not surpassed the yield point should be divided with 1.5.

$$\sigma = \frac{F}{A} = N/mm^2 \qquad \sigma_{allowed} = \frac{1350}{1,5} = 900N/mm^2$$

A spring steel strip of 1-1.5 mm in thickness would thus withstand tensions of approximately 900 N/mm^2 without deformation. To find out how much a cross section of the steel would resist bending the formula for the section modulus (S) was used, where b is the width and h the height. See table 1 in the results for the section modulus of the chosen sizes of spring steel.

$$S = \frac{bh^2}{6}$$

The steel was bent at en even curve and this bend acts as a lever and has to be considered in the calculations. The torque (τ), lever action, is produced multiplying the force applied with the length of the lever arm (r). The maximum tension applied is thus:

$$\sigma_{max} = \frac{\tau}{S} = \frac{F * r}{S}$$

To calculate the maximum force tolerated by the steel without deformation the formula is converted and reads:

$$F = \frac{S * \sigma}{r}$$

The results from these calculations can be read in table 1 in the results section.

Method for calibrating and validating the meter

The large and medium rein tension meter were calibrated by lifting ten known weights from 0 to 20 kg using one rein at the time. The small rein tension meter was calibrated with 14 known weights from 0 to 30 kg. See table 2 and figures 6 and 7. The tension meters with the perpendicular strain gauges (right meter of large and medium meter) initially showed no changes of output voltage when subjected to strain. It was found out that this setup of the strain gauges compensates for bending strains and is instead appropriate for longitudinal strains. This is due to the electricity flowing from the strain gauge parallel to the long side on the one side to the strain gauge perpendicular to the long side on the same side (the setup for the strain gauges should be slightly different for the perpendicular type, the strain gauges numbered 1 and 2 are on one side and 3 and 4 on the other side of the material). The electrical circuit was thus altered so that the electrical current flowed from the parallel strain gauge on the one side to the one on the other side. Electrical output was then received from the right rein of the large and medium meter as well, but measured over two strain gauges only.

The offset was set so that the meter started measuring immediately and thus would react to very light tensions. The range of the voltage output received from the IMU was 0-2.56 V. The Wheatstone bridge circuit is temperature compensated in its design, yet the tension meters were both sprayed with cold spray and heated with a hot air gun and the signal was studied for changes of voltage.

Field testing of the rein tension meters was performed to assess the ease of operation, the fitting on the horse and the durability and range of the meters. The rein tension meters were tested on seven different school horses and students at the local riding schools. Five horses were ridden with the large rein tension meter and two horses were ridden with the medium one. The students rode the school horses with the rein tension meters during their normal lessons lasting for about one hour. The horses were ridden in walk, trot and canter and in some lessons they were also jumping obstacles. The small rein tension meter was tested with two privately owned horses and their riders. Data were collected at 128 Hz.

Data analysis

The maximum force the steel would withstand without plastic deformation was calculated by using the formula for maximum tension described above (table 1). The small rein tension meter was calibrated three times in a row to test the stability of the voltage output to the same weight. The calibrations were then used to describe the relationship between the voltage output and the rein tension applied. A polynomial regression of this relationship was calculated in Matlab using the polyfit and polyval commands. The calibrated voltage output from the large, medium and small rein tension meter were compared graphically in figure 4. The rein tension data obtained from the field testing were transformed into kilograms and the mean values of the mean (STD), median, minimum, maximum, and the fifth and ninety-fifth percentile of the rein tension data for the left and right rein was calculated in Matlab (table 3).

Results

The weight of each fully equipped meter was 50 grams for the large meter, 45 grams for the medium one and 37 grams for the small meter.

Steel durability

The maximum force each size of steel could withstand is presented in table 1 and it was found that durability increased with an increasing thickness (height) i.e. an increasing section modulus. At the bottom of the table are the calculations from the actual meters with the correct radius of the bend (length of lever) and it demonstrates that the bend also affects the ability of the steel to withstand plastic deformation (maximum force). A smaller bend increases the durability while a larger bend decreases it. Comparing the three sizes of stainless strip steel, the small rein tension meter (30*1.5 mm) was the most durable because it was made of the thickest steel (last row in table 1). By increasing the thickness of the steel by 0.5 mm the durability i.e. the resistance to plastic deformation, was approximately doubled.

Table 1. The maximum force tolerated without plastic deformation for a range of different size spring steel strips SS 1770-04. The maximum force increased with an increasing section modulus and an increasing height.

Size meter	Width*height (mm)	Section modulus (S) mm3	Tension (σ) N/mm2	Length of lever (r) mm	Maximum force N	N converted to kg
Medium	35*1.0	5.83	900	20	262	27
Large	40*1.0	6.67	900	20	300	31
	30*1.2	7.2	900	20	324	33
	35*1.2	8.4	900	20	378	38
	40*1.2	9.6	900	20	432	44
Small	30*1.5	11.25	900	20	506	52
	35*1.5	13.13	900	20	591	60
	40*1.5	15	900	20	675	69
Medium	35*1.0	5.83	900	18	292	30
Large	40*1.0	6.67	900	22	273	28
Small	30*1.5	11.25	900	12	844	86

Calibration

The right rein of the large and medium meter were less sensitive to changes of strain but had a larger measuring range compared to the meters made with four parallel strain gauges (data not shown). However, the large and medium meters were both used in field testing (in spite of the faulty design of the right rein) and rein tension data received have been used for calculating rein tension applied at the riding school. For the four parallel strain gauge meters, all levels of amplification above 279 times resulted in a higher resolution of the measurements but a reduced measuring range of the meter. The amplification level of 279 times yielded measuring ranges of 0 to <15, 20 and >30 kg (figure 6) yet with adequate resolution. Lower amplification levels than 279 times were not tested because the resolution would then be insufficient. The variation in voltage output between the meters depends on the quality of the steel, thicker steel being sturdier with less give to tension.

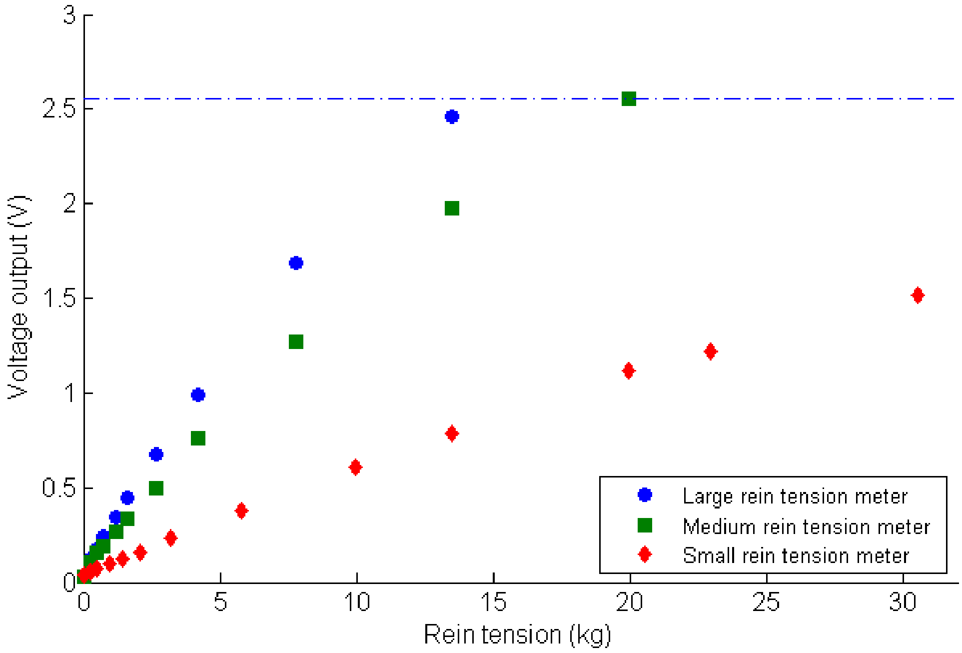


Figure 6. Calibrations of the left rein of the large, medium and small rein tension meter with strain measured over four strain gauges in the Wheatstone bridge. The maximum range of the voltage output is 2.56 V. The large rein tension meter first run out of voltage range.

The repeated calibration of the small meter showed a stable voltage output between measurements as can be seen in table 2. No changes of voltage were found when the tension meters were subjected to heat or cold (data not shown).

Table 2. Repeated calibrations (Cal1-3) of the left and right rein of the small meter. The voltage output is more or less identical between measurements.

	Voltage output					
	Left rein tension meter			Right rein tension meter		
Weight (kg)	Cal 1	Cal 2	Cal 3	Cal 1	Cal 2	Cal 3
0	0.035	0.035	0.035	0.037	0.037	0.037
0.29	0.057	0.055	0.055	0.050	0.050	0.050
0.49	0.068	0.068	0.068	0.066	0.065	0.065
0.96	0.095	0.094	0.094	0.093	0.092	0.092
1.43	0.120	0.121	0.120	0.122	0.122	0.122
2.11	0.165	0.159	0.160	0.161	0.161	0.161
3.22	0.227	0.230	0.230	0.230	0.230	0.230
5.79	0.379	0.378	0.378	0.382	0.379	0.379
9.97	0.609	0.607	0.605	0.621	0.616	0.614
13.49	0.801	0.795	0.789	0.813	0.808	0.805
19.98	1.177	1.151	1.116	1.178	1.164	1.136
22.97	1.225	1.222	1.217	1.261	1.253	1.245
30.56	1.533	1.520	1.518	1.587	1.582	1.575

The small rein tension meter was calibrated up to 30 kg and polynomial regressions visually fitted the data best. The polynomial relationship between the force applied and the electrical output received is described in figure 7. The polynomial calculation shown is for the left rein. Similar values were found for the right rein.

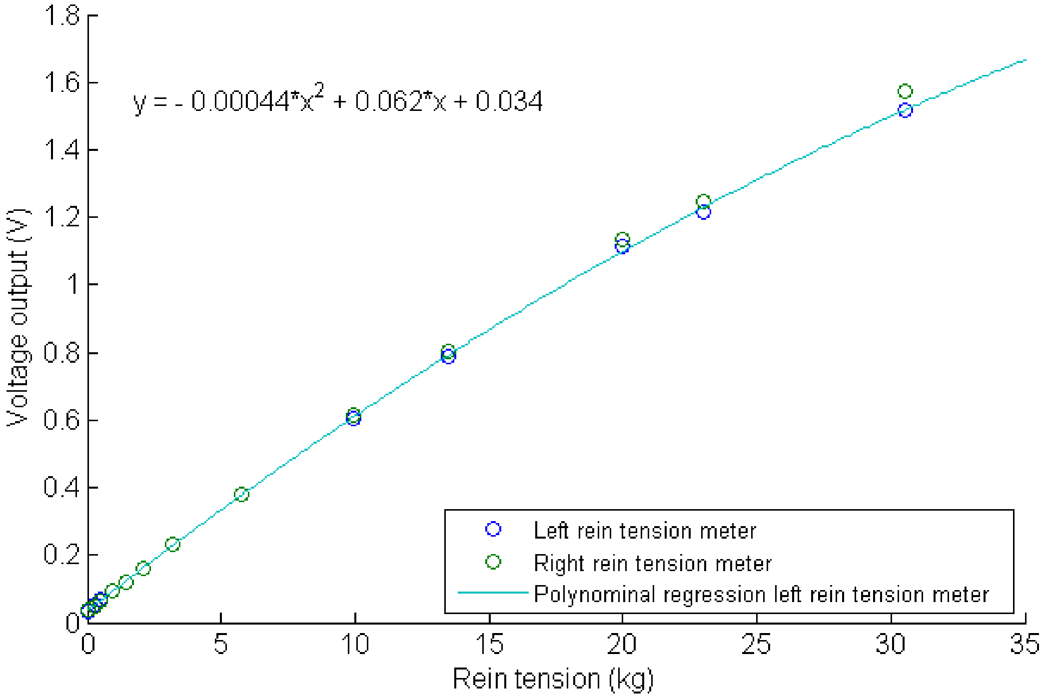


Figure 7. The calibration, polynomial regression curve (R^2=0.9998, left meter) and equation (left meter) for the small rein tension meter.

Riding with the rein tension meter

The initial field testing at the riding school resulted in the left rein of the medium rein tension meter being deformed plastically when rein tension reached over 20 kg. This could be seen in the data set as the zero level increasing to around 2.4 kg without ever returning (figure 8). The measuring range of maximum 2.56 V was surpassed for the left rein of the large and medium rein tension meter in this initial testing. This can also be seen as flat peaks i.e. missing data in the data set, in figure 8. For unknown reasons the IMU did not register any data in one trial with the large meter and rein tension data was thus received from six horses instead of seven.

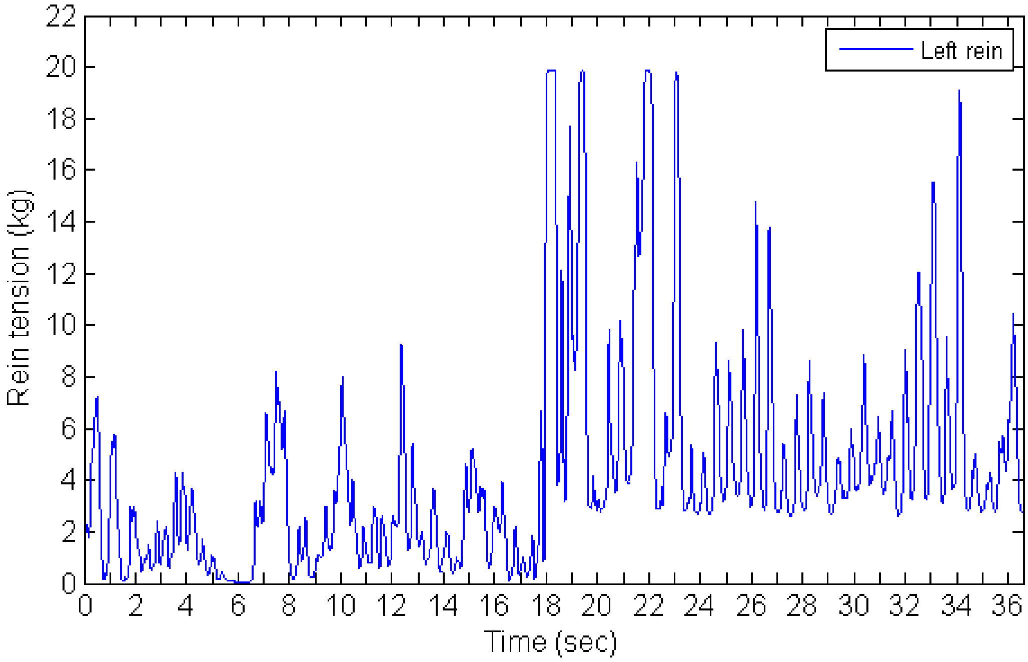


Figure 8. 36 seconds from the riding at the riding school with the medium rein tension meter. The first 18 seconds in the figure are trot, at second 18 there is a canter depart taking place and the rest of the time is canter. Deformation took place at second 18 after a high tension load had been applied. The zero level was dislocated to around 0.65 V which is about 2.4 kg. The flat peaks at second 18 and 22 indicate that the tension applied was higher than the measuring range of the tension meter. The figure shows the left rein only.

The rein tension meter was quickly and easily attached to the horse’s bridle by exchanging the horse’s reins for the reins already equipped with the tension meters, securing the IMU with Velcro just below the browband and securing the cables alongside the bridle. All riders stated that the rein tension meter did not interfere with their riding or use of the reins. The mean of the mean rein tension from the seven school horses was 1.20 kg (STD 1.38 kg) for the left rein and 1.11 kg (STD 1.44 kg) for the right rein. The maximum rein tension values were ranging from 13.68-14.85 kg for the left rein and 13.87-31.58 kg for the right rein, the mean of the maximum rein tension was 14.01 kg for the left rein and 20.75 kg for the right rein. The minimum value was 0 for all riders, i.e. no rein tension. The highest maximum value observed, 31.58 kg, was registered by the right rein of medium tension meter with the same horse that deformed the left medium meter. This horse was known to be difficult to stop and steer and would frequently run off with the rider during the riding lesson. The data from the deformed left medium rein tension meter was not included in the calculations of mean values. Further, as the left large tension meter had a measuring range of 0 to <15 kg and it was surpassed at numerous occasions, the mean and maximum value for the left rein should likely be higher and more resembling the values of the right tension meter. The two privately owned horses had a mean rein tension of 0.51 and 0.52 kg for the left rein and 0.37 and 0.44 kg for the right rein with maximum rein tensions of 5.29 and 6.52 kg for the left rein and 6.1 and 6.32 kg for the right rein. Rein tension values for each individual horse is presented in table 3.

Table 3. Rein tension values of each individual horse ridden with the rein tension meters.

Size meter	Horse	Rein	Min	5th percentile	Median	Mean	STD	95th percentile	Max
Medium	School horse 1	right	0	0.02	0.57	1.18	1.81	4.16	31.58
Medium	School horse 2	left	0	0.16	0.77	0.95	0.87	2.21	14.85
		right	0	0.02	0.41	0.66	0.87	2.04	18.08
Large	School horse 3	left	0	0.02	0.87	1.59	2.13	4.78	14.07
		right	0	0.02	0.56	1.19	1.84	3.72	26.16
Large	School horse 4	left	0	0.02	0.48	0.99	1.26	3.36	13.75
		right	0	0.01	0.35	0.86	1.25	3.19	13.87
Large	School horse 5	left	0	0.02	1.44	1.71	1.44	3.77	13.71
		right	0	0.01	1.72	1.99	1.61	4.41	18.77
Large	School horse 6	left	0	0.02	0.29	0.76	1.22	2.61	13.68
		right	0	0.01	0.31	0.80	1.25	2.78	16.01
Small	Private horse 1	left	0	0.22	0.29	0.51	0.43	1.54	5.29
		right	0	0.02	0.17	0.37	0.45	1.21	6.09
Small	Private horse 2	left	0	0.28	0.38	0.52	0.39	1.35	6.52
		right	0	0.07	0.28	0.44	0.42	1.17	6.32
	MEAN		**0**	**0.06**	**0.59**	**0.97**	**1.15**	**2.82**	**14.58**

Discussion

The design of the meter

After testing the rein tension meter in several different ways it was found to be both durable and accurate and well suited for rein tension measurements. While the rein tension meter can be plastically deformed from strain, the use of a piece of bent stainless spring steel as the building block for the rein tension meter made it unbreakable in its design. Further, draping intact leather reins over the metal bend makes for a safe product with no risk of broken contact with the horse’s head. In other words, a broken rein tension meter does not compromise the safety of the horse and rider. To further validate and test the durability and range of the meters, each tension meter could have been tested in a tensile test machine. In tensile testing the material tested is subjected to a controlled force that can be increased until the material becomes plastically deformed or breaks. By studying the voltage output generated in the rein tension meter simultaneously the upper measuring range of the small meter could have been found out.

The vulnerability of the meter lies in the electrical contacts which have to be thoroughly attached and protected from strain. As durability mainly increased with an increased thickness of the metal, the rein tension meter could thus be produced from a smaller piece of steel than was initially tested. This was an advantage as it weighed less than the first prototypes and thus caused less interference with the reins. The weight of 37 grams for the small meter is comparable to other rein tension meters used in research (Clayton et al., 2003; Heleski et al., 2009).

The attachment of the rein tension meter to the rein could be improved as it requires a screwdriver and wrench to attach and detach the screws and lock nuts. Other types of attachments were discussed but a well-functioning solution has not yet been found. The attachment has to withstand the same maximum strains as the rein tension meter and still have a quick and easy attachment that requires no tools. Making the rein tension meter wireless was also discussed, but not applied, since that would lead to a more complicated design, more expenses and a larger meter. The placement of the data logger, the IMU, below the browband had the advantage of both recording the horse's head movement and allowing the cables to run along the bridle, close to the horse's head, with little risk of them being entangled and broken.

The strain gauge technique

Strain gauge technique for measuring strains is well suited for rein tension measures, as both very small changes of resistance and heavy loads can be measured. The rein tension meters with the perpendicular strain gauges worked to satisfaction after altering the circuit. However, it is recommended to use the parallel pairs of strain gauges for more accurate measurements. If a rein tension meter relying on strain gauge technique does not return to the same zero level during or after measurements, it can be expected to be caused by poor attachment of the strain gauge to the material underneath, force still being applied at some extent to the material underneath or plastic deformation of this material. The problems described in the introduction concerning the Signal Scribe rein tension meter are likely not due to the strain gauges themselves, but rather the construction of its building blocks and the durability of the electrical components.

There were some problems with non-returning zero values during the first calibrations of the meters. From the beginning the rein was firmly attached at both ends of the spring steel. When a heavy load was applied, the leather rein slipped to a small extent underneath the steel pinch so that when tension was released, the rein still pressed against the metal. The problem was solved by detaching the rein at one end and letting it run loosely underneath the steel plate.

Utilizing the rein tension meter in horseback riding

The field testing was informative and added information on how the rein tension meter needed to be adjusted and modified. How much strain the rein tension meter could withstand, the appropriate measuring range, the attachments to the horse and the ease of managing the meter with the horse was found out. For example, additional Velcro straps were attached to the cables after the first field testing.

It is unknown how much rein tension led to the medium meter being permanently deformed since the strain surpassed the measuring range of the meter. The medium rein tension meter could withstand a maximum strain of 30 kg (table 1) and when deformity took place the tension on the reins likely reached beyond that as the right rein of the same horse registered a maximum tension of 31.58 kg. However, as this horse was unusually hard to control via the reins, it is believed that the measuring range of the small rein tension meter of >30 kg is still enough to register most horses and riders. To increase the precision in the rein tension measurements a higher resolution for the data (16-bit instead of 12-bit) could have been implemented. This would have yielded more information about subtle rein tension signals, in particular when very light cues are given to the horse.

The value of using a rein tension meter

Rein tension is a large part of the communication between horse and rider and a rein tension meter can be a valuable tool in research on horse-rider interaction as well as for the individual rider and the riding instructor. There is still more to learn and investigate about rein tension; what constitutes a rein signal, how does the horse discriminate between pressure variations in rein tension and rein signals and how small and fast changes of rein tension can be perceived by the rider?

A limitation of the rein tension meter is that it is impossible to know whether the tension is increased by the rider pulling the reins or the horse pushing against the bit. Therefore additional information, like the position of the horse’s head, the gait and speed of the horse as well as synchronizing the rein tension data with the stride cycle and studying the horse’s behaviour should help to evaluate why and how rein tension increase or decrease. The accelerometer in the IMU attached on the horse’s forehead can potentially yield information of the head position and head movement of the horse as well as yielding gait and stride cycle data. Collecting rein tension data and simultaneously receive data of the horse’s head position and movement should yield information of value for research on the interaction between horse and rider. To safeguard the welfare of the horse, training techniques and rider performance need to be measured and evaluated and a tool like this rein tension meter makes it possible to monitor, at least in part, the interactions taking place between horse and rider.

Conclusion

A durable and accurate rein tension meter can be built by relatively simple means. Pairs of parallel strain gauges are appropriate to use for registering pulling forces applied on bent steel. The small size meter generated improved results compared to the large and medium meter by being more durable and having a larger measuring range. The use of the accelerometer data generated in the IMU can potentially be used to identify the horse’s gait and moment in the stride cycle and is synchronized with the rein tension data. The study of rein tension can and should be developed to increase the understanding of the interactions taking place between horse and rider and hopefully both horse welfare and performance can improve.

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Manufacturers' addresses

Excel, MS Excel, Microsoft Corporation, Redmond, WA
HBM Sverige, Reprovägen 6, 183 77 Täby, Sweden
Matlab ®, The MathWorks Inc, Natick, Massachusetts, USA
ROLAB i Uppsala AB, Box 9018, 750 09 Uppsala, Sweden
x-io Technologies Limited, United Kingdom http://www.x-io.co.uk

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