Test bench for the measurement of scissors' cutting torque

M. Tarabini
Dip. Di Meccanica
Politecnico di Milano
Milano, Italy
marco.tarabini@polimi.it

D. Magnani
School of Industrial and Information Engineering
Politecnico di Milano
Milano, Italy
davide.magnani@mail.polimi.it

H. Giberti
Dip. di Ingegneria Industriale e dell'Informazione
Università di Pavia
Pavia, Italy
hermes.giberti@unipv.it

G. Gianola
Consorzio PREMAX
Premana, Italy
giovanni.gianola@premax.it

P. Marzaroli
Dip. Di Meccanica
Politecnico di Milano
Lecco, Italy
pietro.marzaroli@polimi.it

S. Marelli
Dip. Di Meccanica
Politecnico di Milano
Milano, Italy
stefano.marelli@polimi.it

***Abstract*— This work describes a test bench developed to measure the cutting torque of scissors as a function of the blades position. The prototype of the machine has been validated by evaluating repeatability and reproducibility of torque measurement while cutting fabric. The dependence of the measured torque from parameters such as the scissors' wear, cutting velocity, fabric pre-tensioning and fabric mechanical properties were investigated. The scissors' wear has been investigated by analysing results of more than 20'000 consecutive cutting cycles. The study sets the bases for the creation of the equivalent of ISO 8442-5 (2004) for scissors.**

Keywords—sharpness, scissors, industry 4.0, measurement

I. INTRODUCTION

The edge sharpness is the defining feature of cutting tools; a worn cutting tool requires the application of greater cutting forces to execute the same operation, in respect to a sharp one [1]. Such increase of physical labour, in a working environment, may lead to occupational diseases, such as carpal tunnel syndrome [2], [3], and to a decreased productivity [4]. Many parameters influence the efficiency with which a blade can perform a cut [5]. Some of these parameters are related to the tool itself, like the macroscopic geometry of the whole tool [6] and the microscopic geometry of the edge of the blade. Others are related to how the tool is used, like the angle between the blade and the object to be cut, or the motion with which the cut is performed (cutting, slashing, chopping, etc.).

Given the high number of parameters, and the fact that the physical and mechanical properties of the object to be cut have also a great influence on the process, it is hard to obtain a model able to predict and compare the cutting ability of different tools. Moreover, the edges of all cutting tools wear even during light use [7] and need proper maintenance and sharpening schedules to maintain optimal working conditions. These cycles of wear and sharpening influence the geometry of the tool and its edge, further increasing the complexity of the problem [8]. Therefore, a variety of machines has been produced to test in a reproducible and objective way the cutting efficiency of various tools and compare them between each other.

ISO 8442-5 (2004) regulates the testing procedure of the sharpness of straight blades [9]. According to the regulation, the blade should be pressed against the testing medium and execute a fixed number of cutting cycles, consisting in a forward and backward stroke. All the parameters involved are fixed: cutting force, stroke length, stroke nominal speed, number of cut cycles and cutting medium composition. Through the depth reached by cuts in each cycle it is then possible to compare the performances of different blades. CATRA (Cutlery and Allied Trades Research Association, Henry Street, Sheffield, Great Britain) sells a machine able to perform the tests as prescribed by ISO 8442-5 (2004).

Different authors proposed other machines for testing the sharpness of knives. For example, McGorry et al. [1] proposed a portable system able to evaluate the sharpness of all the portions of the blade. The knife to be tested is fixed horizontally to a rail. A linear actuator moves the knife along a line inclined at a 45° angle, at a fixed speed of 40 mm/s. The medium on which the cut is performed is a strip of polypropylene-coated fiberglass screening, woven into a fabric. This strip is held vertically along the path of the blade, and a force sensor measures the vertical force exerted by the knife during the cutting action. This testing machine allows the repeatability of the tests and the continuous measure of the force; however, after each test an operator must change manually the used cutting medium with an undamaged one. For this reason, this setup may not be ideal for tests requiring a high number of repetitions.

Some machines have been also proposed specifically for testing the cutting efficiency of scissors. One example is the US patent deposited by Walker NEWELL and David Scott Vogel in 2013 [10]. The device works by mimicking the movement of the hand, opening and closing the pair of scissors to be tested against a strip of cutting medium. A potentiometer is used to measure the relative position of the two parts of the scissor, and a force sensor is used to measure the cutting force. This machine can feed automatically intact cutting medium; thus, it can execute many cutting cycles without the need of human intervention.

CATRA sells a machine able to also test the sharpness of scissors. This machine works by clamping one bow of the scissor and moving the other bow through a crank mechanism. The tool must be fixed so that its pin is aligned with the axis of rotation of the crank. A force sensor, positioned in the arm of the crank measures the force necessary to close the scissor

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against a testing medium, across the cutting cycle. The cutting parameters are programmable, and the cutting medium is fed automatically, so also this machine can perform many repetitions without the need for human intervention.

The machines patented and available in the market measure the cutting efficiency of scissors by measuring the linear force needed to close them. This prevents a direct comparison between different models, as the instantaneous closing torque is dependent not only by the force, but by the shape of the handles of the tool. The prototype of a new machine for testing the cutting efficiency of different models of scissors has been developed. The functional requirements were the capability of comparing different models of scissors between each other and the ability to execute and analyse a large number of cutting cycles with a minimal human intervention.

Section II describes the main characteristics of the machine; reproducibility and repeatability tests are described in section III. The effects of parameters such as the scissor wear, cutting velocity, pre-tensioning, and mechanical properties of the fabric on the cutting torque are described in section IV; conclusions are drawn in section V.

II. Bench Design

The test bench for measuring the cutting efficiency of scissors is shown in Figure *1*. The prototype peculiarity is the coupling of a brushless motor with its encoder (1) with one blade of the scissor (2), while the other blade is fixed. The moving blade is glued to an Oldham Joint (5), which ensures the transmission of pure torque even in case of small axial misalignments between the pin of the scissors and the axis of the motor. The cutting torque is measured by a MTRS torque transducer (full-scale 2.5Nm) manufactured by VETEK, Sweden (6). A Scout 55 has been used to condition the torque transducer signal; the analog output of Scout 55 was sampled by the motor board at a rate of 50 Hz.

Two elastic joints MWS20-6-6-SS manufactured by Ruland Manufacturing Co., MA U.S.A. (5, 7) connects the two ends of the torque transducer to the rest of the system, to avoid the transmission of bending moments. The shaft runs on a roller bearing to minimize the friction and to limit the additional torque. Two limit switches (9, 10) ensure the safety of the system. The material to be cut, a fabric used by the *Consorzio PREMAX* (www.premax.it) for internal tests, is continuously fed through a roll, which is unwind by another motor. A weight is hung to the free end of the fabric, providing the preload. A software developed in LabVIEW was used to both acquire the measurement data and to control the movements of the machine. To operate in quasi-static conditions and to prevent screw overheating, the maximum cutting frequency of the machine is 1 cut per s.

During the cutting cycle, the instantaneous torque changes constantly, due to material friction along the blade and scissor geometry. Although different parameters can be extracted from the time history, we decided to summarize the waveform using the RMS (red line in Figure 2 in function of cutting angle measured by the encoder).

Preliminary functional experiments have been carried out on the bench using the most common types of scissors manufactured by *Consorzio PREMAX*. Five new scissors were used in the experimental tests. Two identical pairs (S_1 and S_2) were used respectively in repeatability and reproducibility test. Then, four pairs of scissors (S_3, S_4, S_5 and S_6) were used to characterize scissors' behavior respectively in wear, velocity, mechanical properties of the cutting medium and fabric pre-tensioning tests.

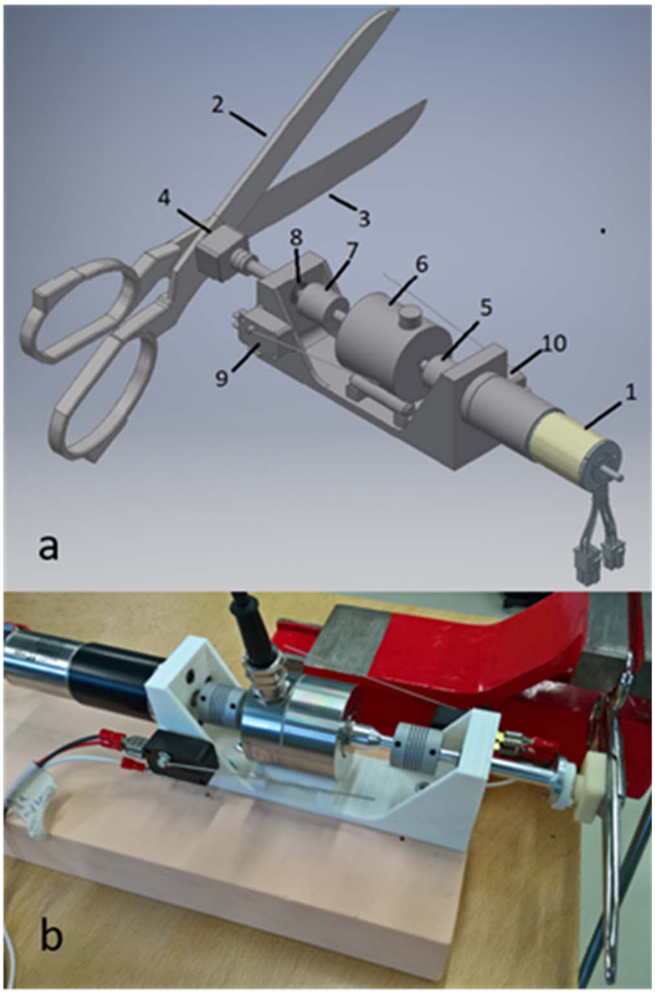

Figure 1: CAD drawing (a) and pictorial view (b) of the proposed machine for assessing the cutting efficiency of scissors.

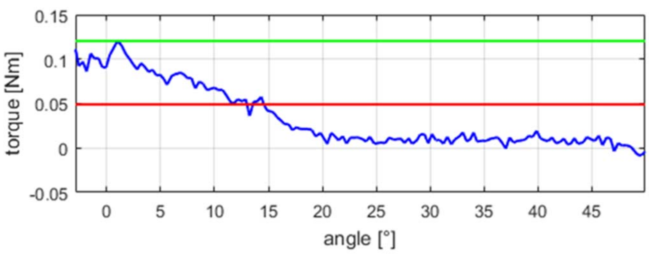

Figure 2: Torque in function of rotation angle of one cut (blue line). Torque RMS evaluated on torque signal (red line) and torque maximum value (green line).

III. Bench Metrological Characterization

The sensitivity of the measurement chain was determined by applying known torques to the free end of the torsiometer mounted in the machine and reading the voltage sampled by the control board. The torque was imposed by hanging calibrated deadweights at a known distance from the torsiometer axis. The uncertainty on the reference torque was

0.3%. The procedure has been repeated for both positive and negative torques. The sensitivity determined by the linear regression procedure was 0.28 N·m/V. The RMS of the residuals was 1.6 N·mm (Figure 3).

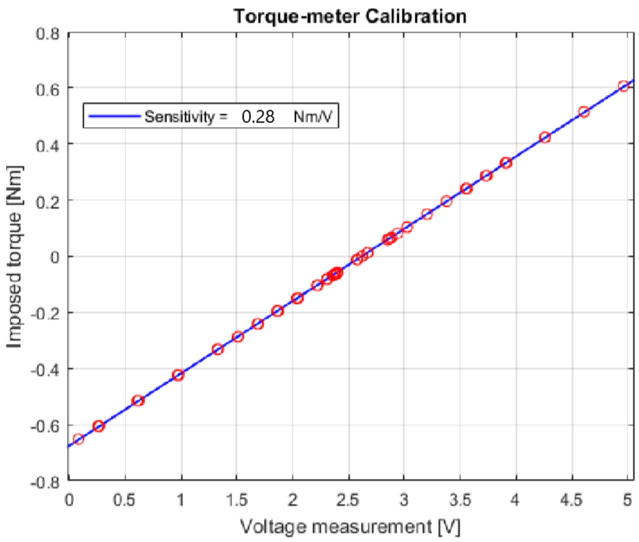

Figure 3: Torque sensor calibration result. Sensor output has been measured in correspondence of known applied torque between ±0.6 Nm.

The measurement repeatability was evaluated on scissors S_1 by measuring the RMS torque in 20 consecutive cuts, with the hypothesis that the variation of the resistance of the material and the tool wear are negligible. Tests were performed both with manual and automatic feeding of the fabric; in these two cases, the torque RMS were respectively 45 ± 2 N·mm and 46 ± 3 N·mm; boxplots of results are presented in Figure 4.

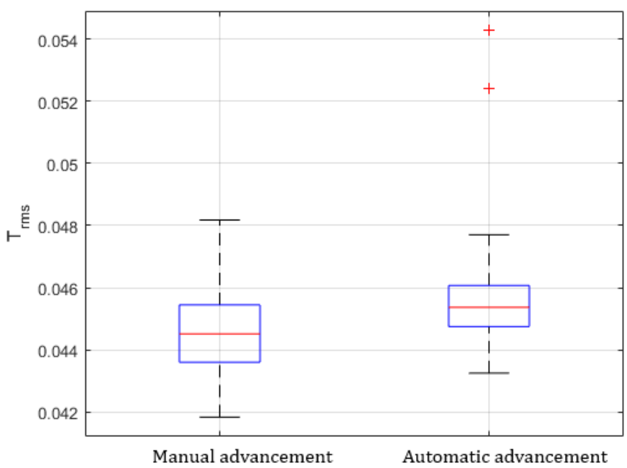

Figure 4: Repeatability of torque RMS value of twenty cuts in case of manual and automatic feeding of the fabric. Torques are expressed in N·m

The standard deviations are in the same order of magnitude of the torque meter uncertainty (1.6 N·mm).

The test bench reproducibility was estimated on scissors S_2 by stopping the machine between cuts to reposition the fabric. The test was repeated for 20 times; reproducibility was quantified by the variation of the RMS torque with respect to the previous cut (ΔT). A new pair of scissors was used; results are shown in Figure 5. ΔT was 1.7 ± 5 N·mm if the material was repositioned between two cuts and 0.9 ± 1.8 N·mm when the material was not repositioned between two cuts.

These values evidence that the instrumental effects are lower than 3 N·mm; this value has been used to discuss the meaningfulness of effects evidenced during the experimental scissors' characterization.

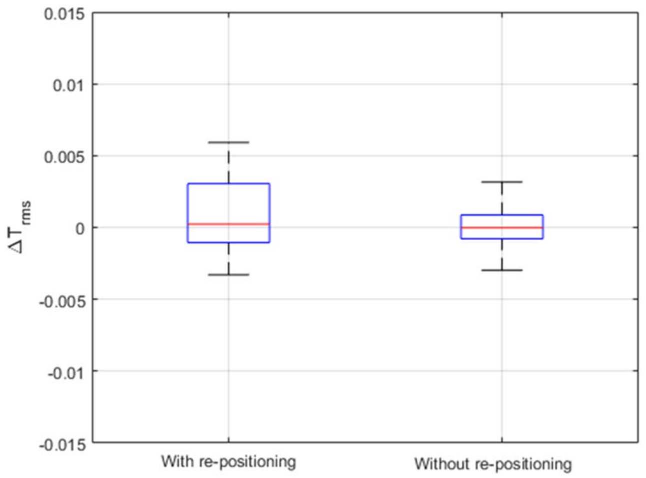

Figure 5: Reproducibility of torque RMS value of twentyfive cuts in case of re-positioning and without re-positioning of the fabric.

IV. SCISSORS CHARACTERIZATION

After the validation of the system and identification of its reliability, the influence of scissor wear, cutting velocity, mechanical properties of the cutting medium and fabric pre-tensioning on cutting torque were investigated.

Data acquired during the wear test (Figure 6) on scissors S_3 show the progressive reduction of torque needed to cut the fabric, which after 20'000 cutting cycles decreased almost linearly from 73 to 41 N·mm. The trend line expression is:

$$T = \alpha_0 \cdot N + T_0,$$

where T is the rms value of the measured torque averaged across the tests done with the same conditions, expressed in N·m, N is the number of cutting cycles. α_0 was $-1.66 \cdot 10^{-6}$ N·m and T_0 was 0.075 N·m. Root mean squared error (RMSE) computed on mean values for each cycle, was 1.2 N·mm.

This evidences that scissors have an initial settling phase and that the friction between the blades decrease in the initial usage.

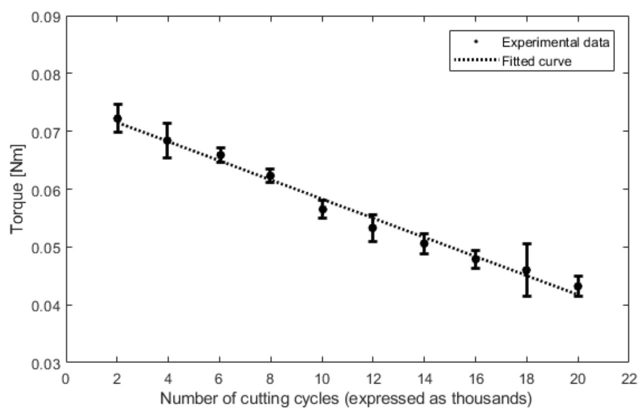

Figure 6: Wear effect on mean value of the torque rms ± standard deviation, measured during 20’000 cutting cycles.

Figure 7 shows the results obtained by changing the cutting speed on scissors S_4. For each velocity 4 cuts were performed, velocity values were tested in randomized order, in the range between 5 °/s to 210 °/s. Results show an increasing trend of the cutting torque with the scissors’ closing velocity; a large data dispersion with respect to the trend line is evident. The trend line expression is:

$$T = \alpha_1 \cdot V + T_1,$$

where T is the rms value of the measured torque averaged across the tests done with the same conditions, expressed in N·m, V is the cutting velocity expressed in °/s. α_1 is equal to $5.83 \cdot 10^{-5}$ N·m·s/° and T_1 is equal to 0.049 N·m. RMSE computed on mean values for each velocity, is equal to 5 N·mm.

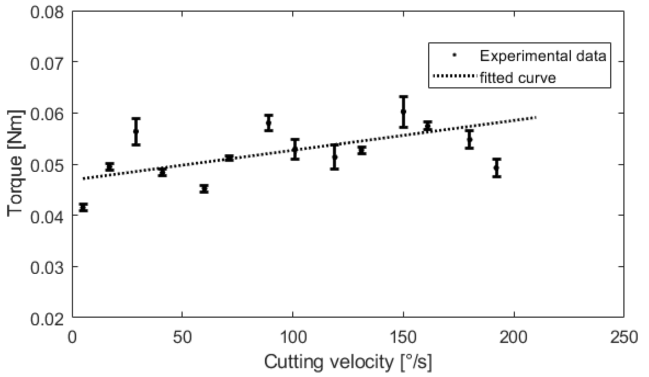

Figure 7: Mean value of the Torque rms ± standard deviation, measured during the cutting cycles with different speeds

Additional tests were performed to identify the effect of the fabric density on the cutting torque on scissors S_5. Results, shown in Figure 8, evidence that the torque increases almost linearly with the fabric density. The trend line expression is:

$$T = \alpha_2 \cdot W + T_2,$$

where T is the rms value of the measured torque averaged across the tests done with the same conditions, expressed in N·m, W is the fabric density expressed in g/m^2. α_2 is equal to 0.005 N·m^3·g^{-1} and T_2 is equal to 0.019 N·m. RMSE, computed on mean values of each fabric density, is equal to 7 N·mm.

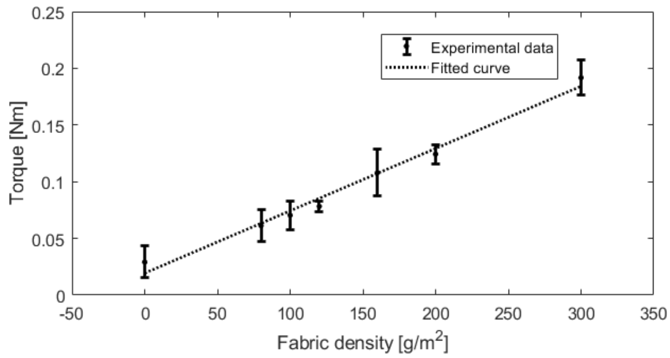

Figure 8: Mean value of the Torque rms ± standard deviation, measured during the cutting cycles with fabrics with different density.

The effect of the fabric pre-tension was analyzed on scissors S_6 by hanging to the free-falling end of the fabric different calibrated weights (from 50 g to 500 g). Ten cuts have been performed for each weight. Figure 9 shows that data acquired with weights equal to 50g, 150g 300g and 500g do not have a clear trend; the data dispersion in some of these tests was variable, reasonably because of the scissor mechanical characteristics

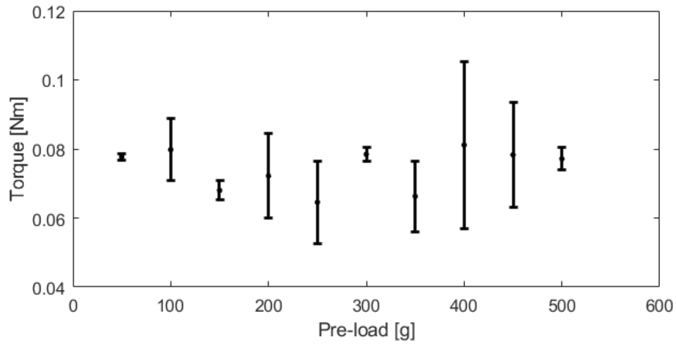

Figure 9: Mean value of the Torque rms ± standard deviation, measured during the cutting cycles with different pre-loads applied to the cutting medium.

V. Conclusion

The prototype of a machine capable of testing the sharpness of scissors has been designed and validated. The cutting efficiency was quantified by the cutting torque; the measurement reproducibility and repeatability were quantified and were lower than 3 N·mm.

In accordance with the results previously presented in the case of knives [5], the main parameters influencing the cutting torque are the mechanical characteristics of the testing medium. The decrease of torque during the wear test may seem contradictory with the idea that a worn blade requires a higher force to perform the cut. It may be linked instead with another aspect of the wear of this kind of tools, which is the loosening of the scissors’ pin, that progressed during the test.

The correlation between the cutting velocity and the torque was limited and the effect of the pre-tensioning of the fabric was negligible.

Preliminary results may give some indications about the relevant parameters of the process to be considered when creating the equivalent of ISO 8442-5 (2004) for scissors. The endurance evidenced a decrease in cutting torque, thus evidencing the need of at least 100’000 cuts to better characterize the scissors wear.

Finally, the machine must be improved to increase the process automation. First, in the current model the cutting medium is preloaded through a dead weight applied to the free end of the unwound cloth. This limits the available length of fabric to the height of the machine above the ground, as once the weight reaches the floor, the intervention of an operator is needed to continue the testing process. To solve this problem, a second roller is needed, around which the material can be continuously wrapped around. This roll must be controlled in coordination with the roll feeding the material to the cutting process, to provide a constant preload.

Another improvement is a system for the automatic centring of the pivot of the scissors with the axis of rotation of the measurement systems. This will further decrease the need for human intervention.

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