STUDY OF THE CUTTING OF FLEXIBLE SHEET MATERIAL USING A VIBRATING BLADE

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Rezumat. *Studiul privind tăierea materialelor subţiri şi flexibile cu o lamă vibratoare este complex. Referitor la numărul foarte mare de tipuri de materiale şi caracteristicile fizice ale acestora, este important să se cuantifice parametrii care influenţează tăierea şi să se urmărească evoluţia lor prin monitorizarea în timpul procesului. De exemplu, diferiţi parametri influenţează calitatea de tăiere, cum ar fi forţele, cuplurile aplicate materialului faţă de lama de tăiere, temperatura şi uzura. În acest scop, în experiment sunt integraţi diverşi senzori în structura maşinii. Toate aceste informaţii ar trebui să permită o mai bună înţelegere a fenomenelor fizice induse de procesul de tăiere. Această lucrare studiază procesul de tăiere a materialelor subţiri şi flexibile şi identifică parametrii de influenţă a procesului. Un test iniţial a fost realizat folosind modelarea analitică a comportamentului lamei şi a forţelor implicate, iar acest lucru a subliniat necesitatea de a ataşa un sistem de control pentru procesul de tăiere pentru a măsura parametrii de influenţă. Este exemplificată o metodă de monitorizare a diferiţilor parametri, care implică proiectarea unui sistem piezoelectric cu senzori pe şase axe pentru forţe/cupluri cu restricţii geometrice puternice.*

Abstract. *The study of cutting flexible sheet material using a vibrating blade is complex. Regarding the very large number of cutting materials types and their physical characteristics, it is important to quantify the influent parameters on the cutting and to follow their evolution by monitoring during the process. For example, different parameters affect the cutting quality such as the forces, torques applied by the material on the cutting blade, the temperature and wear. For this purpose, various sensors should be integrated in an experimental cutting machine. All these information should allow a better understanding of the physical phenomena induced by the cutting process. This paper describes the study of flexible sheet material cutting and the identification of the influent parameters. An initial test was carried out using analytic modeling of the behavior of the blade and the forces involved, and this highlighted the need to attach a control system to the cutting process in order to measure the parameters that were influencing it. A method to monitor the different parameters is explained such as the design of a piezoelectric, six-axis, hollow force/torque sensor with strong geometrical restrictions.*

Keywords: Vibrations Assisted Drilling; Machining Dynamics; Process Modeling

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1. Introduction

Lectra is a French society which develop flexible sheet cutting machine such as fabric, leather or technical textile. The development of these machines is mainly empirical and no cutting model has been established. First and foremost, this development requires an understanding of the cutting phenomena and of the interactions between blade and the material being cut.

Cutting flexible sheet materials using a vibrating blade is a subject that has been studied very little in the literature. This is due mainly to the wide variety of materials to be cut and their very different behaviours. Thus the design of this cutting process is the result more of a succession of empirical choices rather than a search to optimize choices. The aim of this study is to understand what mechanisms are involved and to determine which markers are characteristic when cutting flexible materials in order to define a cutting model. To do this, we must first isolate the parameters that influence the cutting process and monitor their changes as the fabric is being cut.

1.1. Cutting procedure

Figure 1 shows in diagram form a machine for cutting flexible sheet materials. It has four parts:

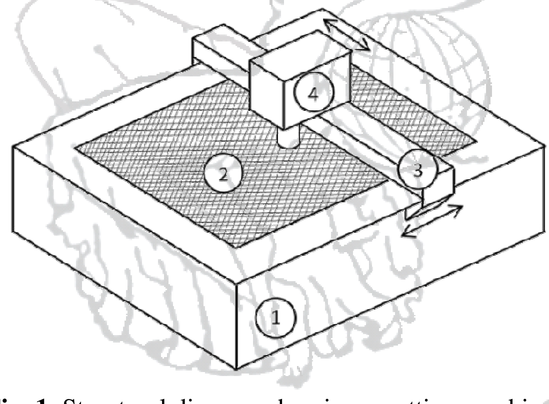

Fig. 1. Structural diagram showing a cutting machine.

- Frame (1).
- Cutting table (2).
- Mobile beam that can move longitudinally above the table (3).
- Cutting head moves laterally above the table carrying the blade and the presser foot (4).

The principle behind the operation of this machine is as follows: the material to be cut is layered into several thicknesses then placed on the cutting table. It is then compressed under a polyethylene film by suction from inside the frame.

The cutting head then arrives above the layers, the presser foot descends and comes into contact with them by the action of a pneumatic jack. Finally, the blade cuts the material with an oscillating movement, moving forward at the same time (Fig. 2).

Note that the blade has freedom of movement along the machine's 3 axes, longitudinal, lateral and vertical and also freedom to rotate around the vertical axis.

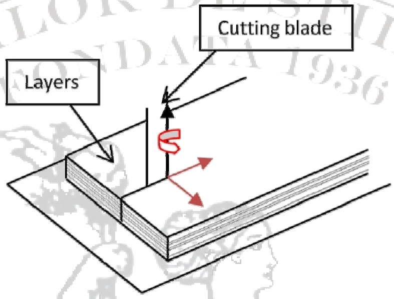

Fig. 2. Diagram showing cutting in a straight line.

1.2. Issues involved

Cutting this type of material poses problems of quality. The blade loses its cutting power as the cutting operation progresses and so needs to be sharpened. This routine action is now carried out at regular intervals throughout the life of the blade, independently of its actual condition as the cutting head is equipped with an automatic sharpening system. When the order to sharpen is activated, the presser foot and the blade lift up and abrasive strips arrive to sharpen both sides of the blade and thus reform the cutting edge.

The frequency at which sharpening is carried out depends on the nature of the material being cut. Settings are adjusted empirically before cutting. In addition, the wear on the blade (loss of material) as a result of the sharpening operation is determined experimentally according to a wear law for abrasion and the number of times it is sharpened, the size of the blade and the type of abrasion used. The position of the cutting edge is calculated according to the number of sharpening cycles carried out. When the blade cuts along a curve, it also bends from the force of the multi-layer of material and geometrical defects appear between the upper and lower layers. To resolve this problem, a force sensor was fixed to the cutting head, inside the presser foot; this movement of the blade could be compensated for according to the forces detected by the sensor (Fig. 3).

Lastly, for some materials with a low melting temperature, the combination of the frequency of the blade oscillations and the speed of cutting can result in the material melting on contact with the blade. The layers of material weld together in the cutting groove and form a solid block of matter. The vibration speed of the blade and its rate of progress therefore have to be reduced whatever the operating conditions in order never to exceed the melting temperature of the material being cut. This phenomenon can greatly affect productivity.

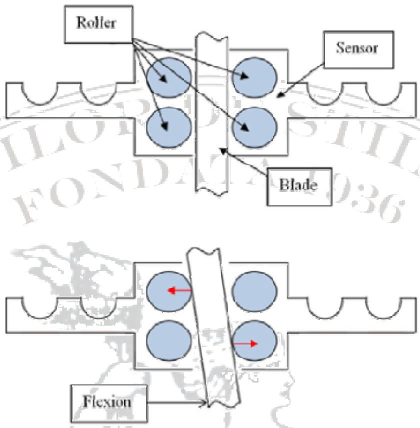

Fig. 3. Functional diagram of torque sensor.

1.3. Architecture of the cutting head

The cutting head is made up of (Fig. 4):

- Vibration block to produce the oscillation of the blade, needed for cutting (1).
- Blade (2).
- Turning blade guide acts as a track for the blade and ensures rotation (3).
- Sharpening system consisting of abrasive strips (4).
- Presser foot, lies flat on the cutting mat and contains the force sensor (5).

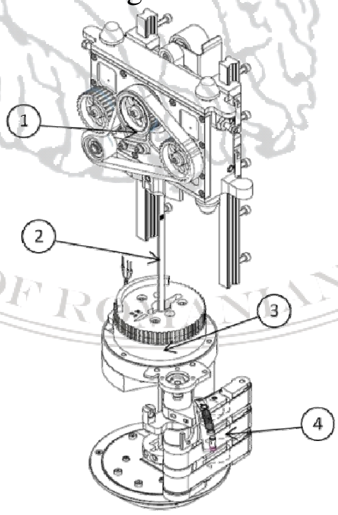

Fig. 4. Internal diagram of cutting head.

The blade is guided by a series of rollers (Fig. 5): 5 in the presser foot, 4 of which act as force sensor, and 8 in the upper blade guide. These rollers bear the forces produced as a result of the cutting process.

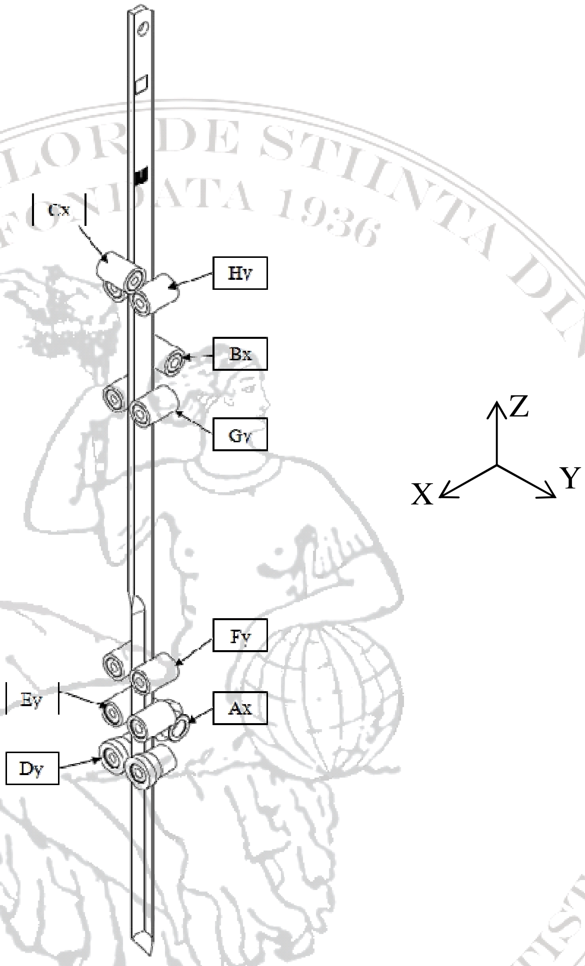

Fig. 5. Blade guided by rollers.

2. Modeling Fabric/Blade actions

2.1. Behavior of the blade

During a straight cut, through a large thickness of material, the blade jumps back a certain distance and pushes strongly against the back roller on the presser foot (Ax).

It should also be noted that when the material opens up as the blade pushes through, this causes friction and a gap in the material, the shape of which can now be estimated after analysing worn blades (Fig. 6):

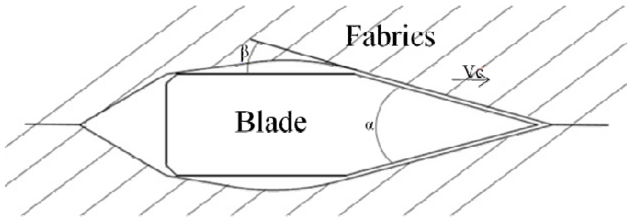

Fig. 6. Straight cut through denim.

When cutting curves (Fig. 7), there is a difference in contact pressure on the fabric from the two sides of the blade.

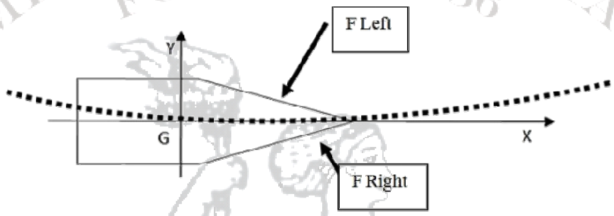

Fig. 7. Blade on curved trajectory.

In the case of a convex curve, pressure increases on the left-hand side and decreases on the right. These components, projected on the *Y* axis, generate a lateral resultant distributed across the entire thickness of the multi-layer of material. This then generates a bending moment in relation to the rollers in the presser foot, which then modifies the trajectory of the blade through the multi-layer.
The torque sensor implanted in the presser foot corrects this phenomenon by ordering a rotation of the blade around the *Z* axis in order to increase its moment of inertia in the *Y* direction (Fig. 8). In addition to this action, the feed speed and vibration speed are modified for increased precision when cutting curves.

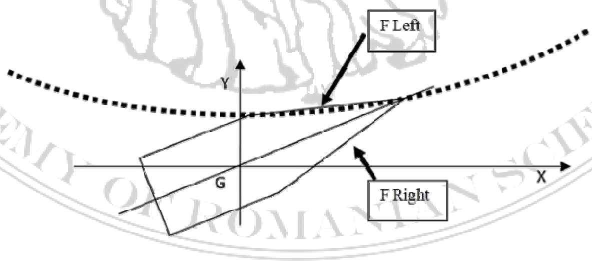

Fig. 8. Blade on corrected curved trajectory.

2.2. Estimating cutting force

The cutting force corresponds to the force required to lift the blade vertically in the fabric multi-layer. This force is able to cut the ripple of material that forms in front of the blade when it is at the 2 dead points at the top (TDP) and bottom

(BDP). An internal study in 1996 was able to estimate this force. This estimate can then be used to quantify maximum force *Fz* max in 50 mm of denim-type fabric with a vibration of 6000 rev/min. If we assume that this force is distributed uniformly along the 50 mm of contact between the blade and the material, this gives a maximum distributed load Pz along the vertical *Z* axis.

2.3. Estimating feed force

By reading power consumption directly, feed force is estimated and assumed to be evenly distributed along the 50 mm of contact between the blade and the fabric, the distributed load is *Px* along the *X* axis.

2.4. Estimating lateral forces

Without the presence of the sensor to correct the trajectory, defects observed between the fabric at the top and at the bottom of the multi-layer are of the order of 5 mm. This shows that the load distributed across the upper part of the blade generates a torque at the end of the blade of 5 mm. An inverse method is used to determine the load that can generate a lateral displacement of 5 mm (Fig. 9).

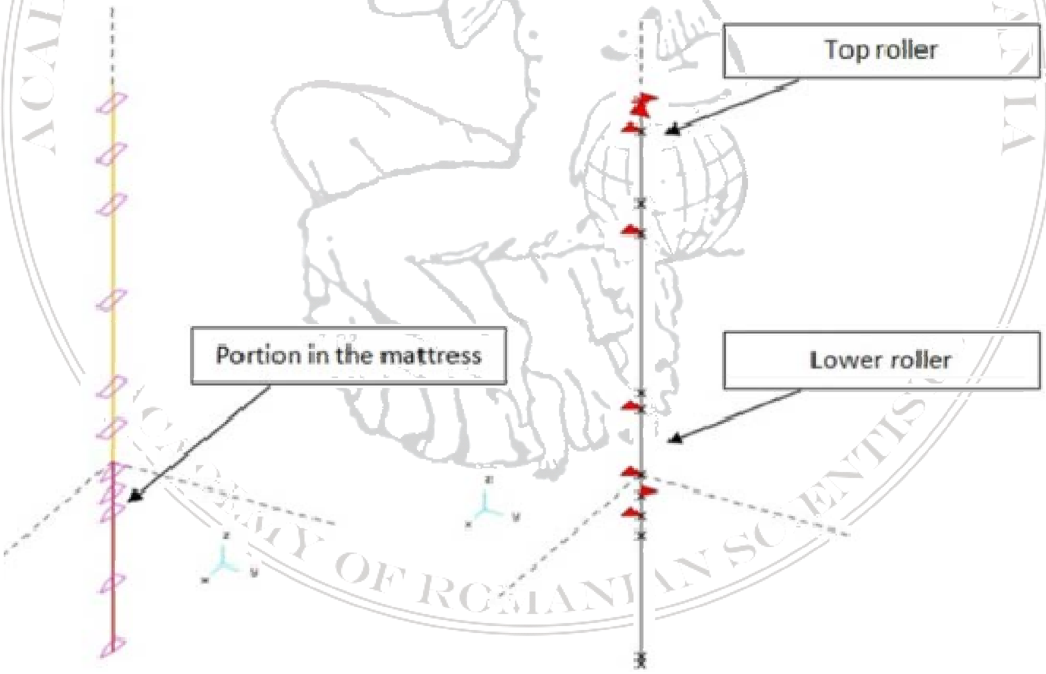

Fig. 9. Modeling the blade with supporting rollers

Using the static analysis software RDM 6 [1], blade distortion and state of stress and the forces in the different rollers are estimated (Fig. 10). The loads producing a 5 mm displacement at the end of the blade can then be deduced.

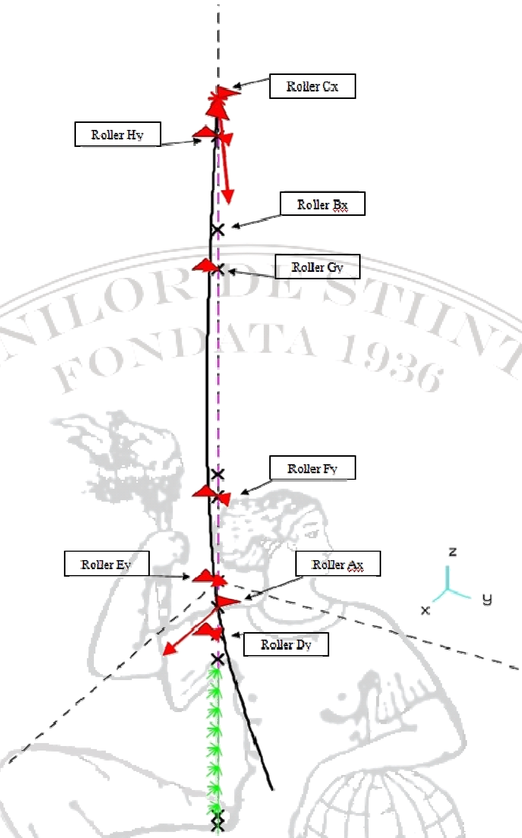

Fig. 10. Blade distorted by lateral force.

2.5. Results

For cutting 50 mm of denim, displacement at the end of the blade is dx = 2 mm (feed torque) and dy = 5 mm (lateral torque).

The contribution of the rollers in absorbing the feed force is as follows:

- Roller *Ax*: 83%
- Roller *Bx*: 0%: This roller serves no purpose as the blade lifts up during cutting by 0.3 mm.
- Roller *Cx*: 17%

And for the torque forces:

- Roller *Dy*: 50.6%
- Roller *Ey*: 42.7%
- Roller *Fy*: 5.9%
- Roller *Gy*: 0.5%
- Roller *Hy*: 0.3%

The rollers in the presser foot (*Dy* and *Ey*) absorb 90% of the load due to the torque along Y. These rollers are closest to the cutting process. This study of the distribution of forces in the blade's kinematic chain clearly show the important contribution made by the rollers in the presser foot compared to those placed above.

When studying torque, it would appear that examining only the 4 lower rollers would be sufficient to analyse the movement of the blade.

2.6. Cutting parameters

When cutting, the operator must select which parameters are to be used. The following parameters: cutting frequency *f*, amplitude *A*, feed speed *Vc*, have a direct impact on the machine's performance. In addition to the speed of cutting or the aesthetic appearance of the cut edges, the forces applied to the blade are also modified.

Like the digital controls on modern machine-tools, the motor currents for feeding along the axes are constantly monitored to ensure that the pre-programmed settings are satisfied. Kim et al. [2] propose a block diagram model of three linear axes of a milling machine. A transfer function linking the force according to the axis being studied and to the strength of the power supplied to the motor is obtained for each axis. This method is applied to a textile cutting machine when cutting a straight line through 42 layers of denim (Fig. 11).

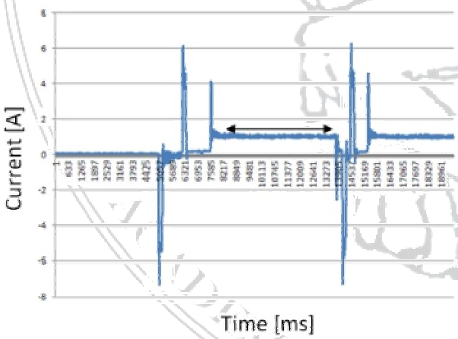

Fig. 11. Power consumption during cutting.

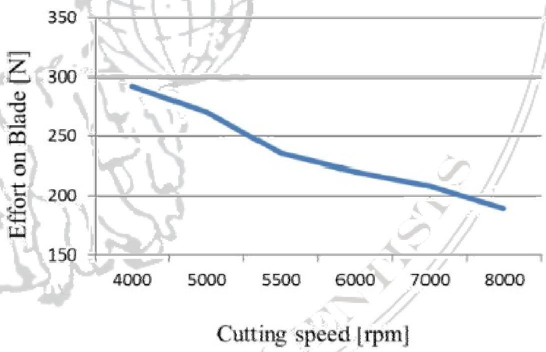

Fig. 12. Change in cutting force with speed.

In qualitative terms, the forces used for cutting tend to decrease as cutting speed increases (Fig. 12).

Unfortunately, these results are to be interpreted with great caution as the process for obtaining them did not produce replicable results and moreover, results differed from one machine to another, despite using the same cutting parameters. A more reliable way of measuring force will therefore be installed in the machine to confirm these first results.

3. Influential parameters

In all these descriptions, several parameters seem to be key for ensuring cutting quality (Figure 13).

These parameters will be measured throughout the cutting operation:

- Different forces and moments applied to the cutting blade,
- Blade wear,
- Temperature of the blade,
- Thickness of the multiple layers being cut,
- Parameters for controlling cutting (speed, amplitude, etc.),
- Pressure holding down the presser foot on the materials to be cut.

As far as possible, in order to be as close as possible to the cutting operation, these measurements will be taken inside the presser foot.

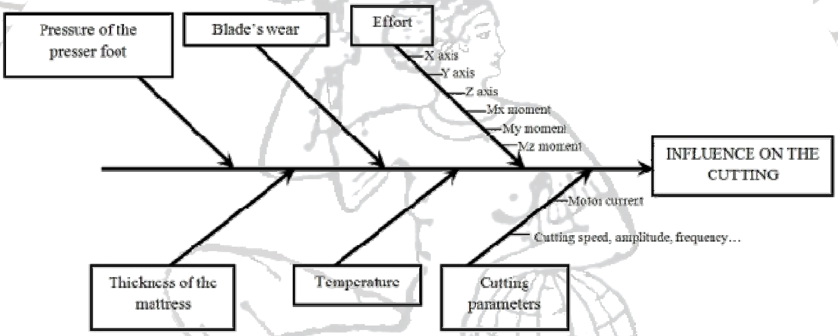

Fig. 13. Parameters that influence cutting.

4. Measuring force

4.1. Dynamometer

The main issue will be that of incorporating a six-component dynamometer (3 forces and 3 moments) inside an extremely small space. The first three components will be used to measure with precision the frontal and lateral forces and also the vertical cutting forces. Knowledge of the moments will be needed to correct the orientation of the blade in curved cutting and to know the exact position of the cutting edge. Measuring must be exact and dynamic because the estimated forces are fairly small and are applied for only a very short time. In addition, in order to maintain cutting quality, the test specimens used should be as stiff as possible. The dynamometer should incorporate the blade and the blade guide via the rollers. This guiding should also be able to be disassembled so that maintenance can take place should the blades break, for example. Lastly, the height available to house the dynamometer is very limited (28 mm). Dynamometers currently use mainly two types of sensor: strain gauges or piezoelectric sensors.

4.2. Architecture of a dynamometer based on piezoelectric sensors

Measuring the six components of the cutting actions requires the use of several triaxial sensors. Dynamometers in the literature use four triaxial sensors. However, research by Li et al. [3] shows that the arrangement, orientation and number used are usually not justified. In addition, the limited space available in the presser foot means that we are unable to place so many sensors there. As using two sensors would leave the upper plate too mobile and likely to rotate, using three triaxial piezoelectric sensors distributed at 120° is a good compromise (Fig. 14).

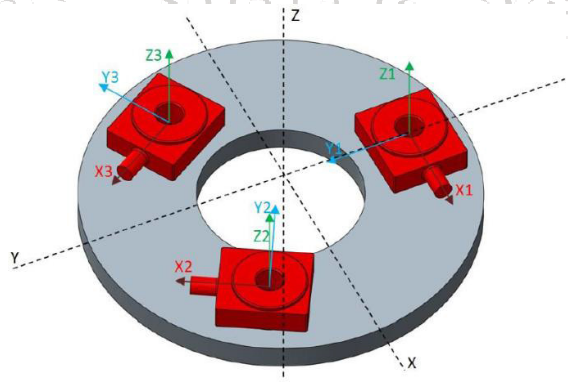

Fig. 14. Placement of the piezoelectric sensors

This dynamometer is based on work carried out at the University of Bordeaux on modelling the twisting cutting action in a milling machine by Albert [4].

At the centre of these sensors will be placed the roller holder carrying *Dy* and *Ey* rollers and the rear roller *Ax*. This part will be removable and will guide the blade in its centre. During a cut several forces will be applied to the blade which will transmit them to the rollers. Then, the rollers will guide these efforts until the sensors (Fig. 15). A calibration matrix will transform the electrical signals in order to traduce them in forces and torques which are applied to the blade.

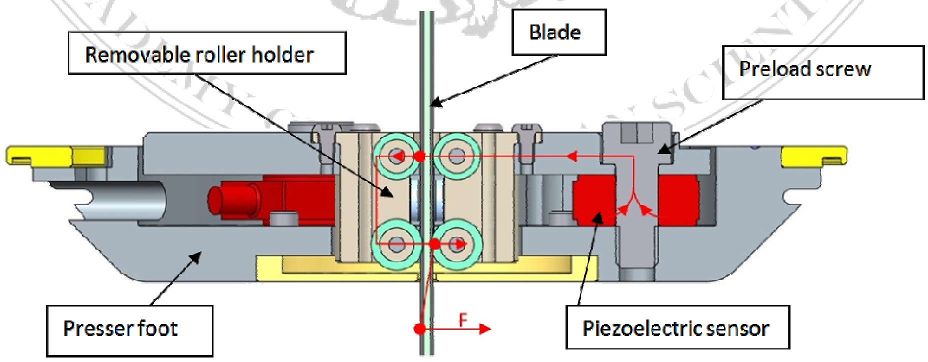

Fig. 15. Operating principle of the piezoelectric dynamometer.

5. Conclusion

The aim of this research is to understand the mechanisms involved when cutting flexible sheets of material using a vibrating blade.

After studying the operation of a typical machine-tool used for this type of cutting, several parameters were recognized as having an influence on this process. By measuring these parameters throughout the cutting operation, we will have a better understanding of how they evolve. A method for forces monitoring is described here. This is a tiny part of the instrumentation which will be implemented on a cutting head. Once all the sensors are in place, it should be possible to identify behaviour markers during the cutting and to propose a physical model of this cutting process.

R E F E R E N C E S

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