Analysis of residual stresses on guide bar of chainsaw

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Abstract. Problematics of residual stresses is known in engineering practice, but it is often forgotten. They are present in each component. Residual stresses can be introduced into the material not only during the manufacturing process, but also when the equipment is used. Every machine system a special approach to its application during operation. In case of non-compliance with its boundary conditions failure can comply damage of components, which may even lead to complete deterioration of the equipment. The aim of the paper is to point out how improper use of equipment affects residual stresses that can lead to its damage. The most used method for determining residual stresses was used – hole drilling method. The practical part deals with the specific application of the hole drilling method on the selected component – the chainsaw guide bar. The next part of the theses is followed by an evaluation of the results and proposal of solution that will contribute to more efficient use of the given structural element and its lifetime.

1. Introduction
The aim of this paper was to show the influence of improper use of the device on the magnitude of residual stresses. For this purpose was investigated an old damaged chainsaw guide bar. Measurements were made using the hole drilling method on this bar. The results on the damaged and undamaged side of the guide bar were compared to each other. The theoretical basis was mainly literature from the Edition of Scientific and Professional Literature of the Faculty of Mechanical Engineering of the Technical University in Košice about experimental methods of mechanics [1, 2]. Foreign literature from well-known authors, eg. Schajer [3–5] as well as from authors who have contributed to the development of the hole drilling method throughout history [6–10]. The results of this work can contribute to better care of technical equipment.

2. Measurement by hole drilling method
2.1. Selection of the component under investigation
For confirmation and application theoretical knowledge of residual stresses, we decided to prepare an experiment on a real component used in practice. For the experiment, we chose a guide bar from the electric chainsaw Makita model UC3520A with length of guide bar 350 mm (figure 1). We decided to use this bar to check how the improper use of the chainsaw in wood cutting influences the residual stresses on the guide bar. The manufacturer's instructions have not been followed during using the chainsaw; the chain was not regularly grinded to the extent recommended by the manufacturer. Since the chain was blunt, more was pressed on the guide bar to cut like a sharpened chain. Also, the manufacturer's instruction to rotate the guide bar regularly have not been followed to both edges wear
equally. All of this resulted in considerable wear of the guide bar as seen in figure 1. About 3 mm of material was less on one side of the guide bar as a result of excessive friction. At the same time, we can observe on this side of the guide bar a heat-affected area where overheating has occurred since the chain movement.

![Figure 1. Makita UC3520A chainsaw guide bar used in the experiment.](image)

The aim of the task was to determine the residual stresses in the thermally affected area of the guide bar. For comparison, we determine the residual stresses on the other side of the bar, which was not worn at all on the side of cut. We drilled two holes symmetrically at the same distance from the bar axis and compare the results.

### 2.2. Surface preparation and application of strain gauge rosettes

We firstly marked the longitudinal axis on the guide bar, then the line perpendicular to the axis, and finally 2 marks that intersect the perpendicular line at a distance of 20 mm from the axis of the guide bar. The marks are located 120 mm from the right edge of the guide bar. Strain gauge rosettes were applied to these places. The mark at the bottom of the bar is closer to the edge. This is due to the wear which was mentioned in the previous subchapter. After thoroughly cleaning, polishing and degreasing the examined area on the guide bar were applied strain gauge rosettes from HBM, type 1.5 / 120R RY6 (figure 2). This type of rosette was used because it was necessary to get closer to the edge of the guide bar. The rosette has a resistance of 120 Ω ± 0.3 %. Their calibration constants are designated as $a$, $b$, $c$, while $a = 1.91\pm1.5 \%$; $b = 1.89\pm1.5 \%$ and $c = 1.91\pm1.5 \%$. A two-component adhesive of X60 Schnellklebstoff was used to glue the rosette to the component under investigation and the strain gauge rosette was loaded until the adhesive cured.

![Figure 2. Strain gauge used to measure residual stresses on the chainsaw guide.](image)

After removing the load from the strain gauges, the cables were connected to the contacts of strain gauges. There were three strain gauges on each rose, so a total of 12 contacts were soldered to which 12 cables were soldered. The cables were connected to 1300 Gage Instalation Tester from MICRO MEASUREMENTS to verify that the strain gauges have a prescribed resistance of 120 Ω ± 0.3 %. All strain gauges were found to meet this condition. Subsequently, the cables were connected to the P3 apparatus (an apparatus for measuring relative deformation). It was necessary to verify that the strain gauge roses were balanced. For both rosettes, the instrument has shown zero distortions in all three directions, and this means the rosettes are balanced and ready for measurement. The contacts were
preserved with \textit{HBM Protective Coating SG 250} for strain gages for protection (figure 3). The system was ready for hole drilling.

![Figure 3. Applied strain gauges with cable connection and protection against damage to strain gauges.](image3.png)

2.3. \textit{Assembly of hole drilling system}
For drilling was used the \textit{RS 200} machine with \textit{P3} instrument and compressor (figure 4). The chainsaw guide bar was glued to the metal sheet with glue (\textit{X60 Schnellklebstoff}). Than with stencil were marked where the feet of the \textit{RS 200} would stand and they were also glued with the \textit{X60 Schnellklebstoff} two-component adhesive.

![Figure 4. Drilling system – RS 200 drilling tool (1), P3 deformation measuring tool (2) and compressor (3).](image4.png)
3. Evaluation of measurement and calculation of residual stresses
Drilling into the material took place at a thickness of 1 mm. Thus, a hole has been drilled through the entire thickness of the material. To avoid side effects e.g. friction, we drilled in 0.1 mm increments. The resulting deformations were recorded from the P3 after each step into the table. In table 1 is the "undamaged side of the guide bar" and in table 2 is the "damaged side of the guide bar".

| Step | Depth (mm) | Deformations in direction |          |
|------|------------|---------------------------|----------|
|      |            | a (µε) | b (µε) | c (µε) |          |
| 1    | 0.1        | -98    | -30    | -12    |          |
| 2    | 0.2        | -120   | -33    | -10    |          |
| 3    | 0.3        | -157   | -33    | 1      |          |
| 4    | 0.4        | -180   | -26    | 15     |          |
| 5    | 0.5        | -194   | -17    | 33     |          |
| 6    | 0.6        | -197   | -5     | 48     |          |
| 7    | 0.7        | -197   | 6      | 64     |          |
| 8    | 0.8        | -202   | 9      | 69     |          |
| 9    | 0.9        | -205   | 15     | 83     |          |
| 10   | 1.0        | -189   | 25     | 89     |          |

| Step | Depth (mm) | Deformations in direction |          |
|------|------------|---------------------------|----------|
|      |            | a (µε) | b (µε) | c (µε) |          |
| 1    | 0.1        | -156   | -137   | -52    |          |
| 2    | 0.2        | -192   | -157   | -46    |          |
| 3    | 0.3        | -232   | -170   | -31    |          |
| 4    | 0.4        | -260   | -170   | -5     |          |
| 5    | 0.5        | -268   | -158   | 31     |          |
| 6    | 0.6        | -275   | -141   | 65     |          |
| 7    | 0.7        | -322   | -160   | 66     |          |
| 8    | 0.8        | -316   | -151   | 86     |          |
| 9    | 0.9        | -318   | -137   | 96     |          |
| 10   | 1.0        | -312   | -131   | 106    |          |

We used the H-Drill program to calculate specific residual stress values. This program uses several calculation methods – for blind holes, e.g. ASTM E837-01 method, integral and power series method. This program using only one method for through holes – ASTM E837-01 [11]. As we drilled a hole through the passage, we used this method.

After starting the program, we opened a window (figure 5), where we chose the type of rose FAER 03-S and entered there also the material characteristics, which we found from the information on the Internet [12]. The guide bar is made of AISI 4140. Therefore, the material characteristics were: Young's modulus $E = 200$ GPa, Poisson ratio $\mu = 0.3$ and yield strength $R_e = 415$ MPa.
We entered the initial deformation (zero) and the final deformation (after drilling the hole). The program outputs are shown in figure 6 for the undamaged side of the guide bar and in figure 7 for the damaged side of the guide bar. Figures 8 and 9 shows the distribution of deformations along the depth of the drilled hole.

![Figure 5. Selection of rosette type and material characteristics.](image_url)

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![H-DRILL RESIDUAL STRESS CALCULATION](image_url)

**Figure 6.** Results from *H-Drill* for undamaged side of guide bar.
Figure 7. Results from the $H$ - Drill program for the damaged side of the guide bar.

Figure 8. Distribution of relaxed deformations along the depth of hole – undamaged side of the guide bar (x-axis: distance from the surface (mm); y-axis: deflection ($\mu e$)).
Figure 9. Distribution of relaxed deformations along the depth of hole – damaged side of the guide bar (x-axis: distance from the surface (mm); y-axis: deflection (με)).

The program calculated the data for planar stress. Therefore, the table shows the stresses in the directions of the axes $\sigma_x$, $\sigma_y$, $\tau_{xy}$, as well as the principal stresses $\sigma_{\text{max}}$, $\sigma_{\text{min}}$ and the principal shear stress $\tau_{\text{max}}$. The direction of the x-axis is in the direction of the axis of the first rosette (direction $a$). The angle $\beta$ is given in degrees and indicates the deviation of the principal stress $\sigma_x$ from the x-direction in a clockwise direction. The results are presented in table 3.

Table 3. Measured residual stress data from H - Drill program.

|                  | Undamaged side | Damaged side |
|------------------|---------------|--------------|
| $\sigma_{\text{max}}$ (MPa) | 90            | 148          |
| $\sigma_{\text{min}}$ (MPa)  | -14           | 9            |
| $\tau_{\text{max}}$ (MPa)    | 52            | 70           |
| $\beta$ (°)       | -14           | 4            |
| $\sigma_x$ (MPa)  | 84            | 147          |
| $\sigma_y$ (MPa)  | -8            | 9            |
| $\tau_{xy}$ (MPa) | 25            | -9           |

The guiding and substantial value of the residual stress to be taken into account is the value of the principal residual stress $\sigma_{\text{max}}$ (indicated by red) and the angle $\beta$ indicating the deviation from the x-axis. As we can see in table 3, a residual stress on the damaged side has been up to 64.44 % greater than on the undamaged side. By improper use of the chainsaw, we have introduced excess residual stresses into the material, bringing us closer to the material shear and creating a greater risk of plastic deformation.

4. Conclusion
The aim of this paper was to show how improper use of a chainsaw can affect the material properties of its guide bar. Since the guide bar was damaged only from one side, two holes were drilled one on the
damaged and the other on the undamaged side of the guide bar. The measured results supported our assumption that there would be higher residual stresses on the injured side. This in turn affects the resulting material elasticity.

It is worth pointing out how important it is for the consumer to read and follow the instructions manufacturers carefully. However, manufacturers are not responsible for damaged machines caused by improper use.

5. References
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