 doi:10.20944/preprints202001.0257.v1

Article

Hydrostatic bandsaw blade guides for natural stone cutting applications

Ammar Ahsan [1*], Jonas Kröger [1], Kyle Kenney[1] and Stefan Böhm [1]

1 Fachgebiet Trennende und Fügende Fertigungsverfahren (tff), Universitaet Kassel, Kurt-Wolters-Str. 3, 34125 Kassel, Germany; info@tff-kassel.de

* Correspondence: a.ahsan@uni-kassel.de; Tel.: +49-561-804-7702

Abstract: Bandsaws either use fibre or ceramic block or sealed bearings as blade guides. This works well for cutting metals, wood and plastics. However, highly abrasive particles generated while cutting stones, settle between the contacts of the blade and the guides causing wear and premature failure. Hydrostatic guide system as presented in this work, is a contactless blade guiding method that uses force of several pressurized water jets to keep the blade cutting in a straight line. For this investigation, cutting tests were performed on a marble block using a galvanic diamond coated bandsaw blade with the upper roller guides replaced by hydrostatic guides. The results show that the hydrostatic guides help to reduce the passive force to a constant near zero in contrast to the bearing guides. This also resulted in reduced surface roughness of the stone plates that were cut. Additionally, it has also been shown that using hydrostatic guides the bandsaw blade can be tilted to counter the bandsaw drift. This original research work has shown that the hydrostatic guide systems are capable of replacing and in fact perform better than the state of the art bearing or block guides specially for stone cutting applications.

Keywords: Hydrostatic; Blade guides; Bandsaw; Diamond blade; Natural stone; Sawing

---

1. Introduction

Natural stone plates due to their texture and resistance to stains, scratches and heat are used traditionally as countertops, floor and/or wall tiles. In the industry these are cut out of quarried stone blocks using either gang or wire saws. The cutting tools contain segments or beads of sintered diamond in a metallic binder. In several previous publications of the tff institute it has been shown that a bandsaw, specifically with geometrically defined cutting edges, provides a technically and economically more viable method for cutting natural stone blocks [1] [2] [3].

In most cases the bandsaws either use a fibre or ceramic block or a sealed bearing as blade guides (see Fig. 1). This works well for cutting metals, wood and plastics. However, highly abrasive particles, generated while cutting stones, settle at the contacts between the blade and the guides causing the steel blade to wear quickly from the sides and fail prematurely. In order to avoid this problem a contactless guide system is required that makes sure that the blade runs straight while at the same time avoiding any direct contact with the blade guides. This work is intended as a feasibility study for hydrostatic blade guides i.e. using pressurized water jets as a means to guide the bandsaw blade while cutting natural stones.

 doi:10.20944/preprints202001.0257.v1

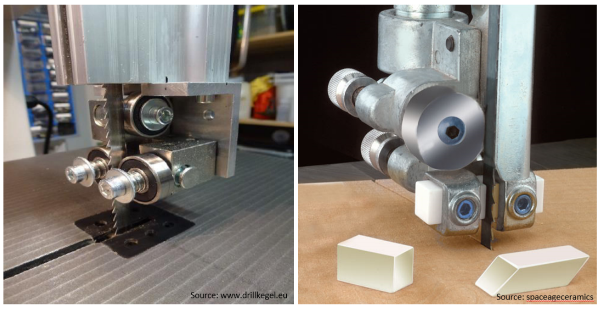


Figure 1. (**left**) Bearing guides. (**right**) Ceramic guide blocks

2. Materials and Methods

A modified version of the KASTOplate U3 bandsaw machine with wheel diameter of 700 mm was used for the cutting tests (see Fig. 2). The maximum achievable cutting speed on the machine was 150 m/min, feed rate 250 mm/min. The workpiece was a 500 mm x 400 mm x 400 mm [lxwxh] block of white Carrara marble. The bandsaw blade used was Wikus Diagrit ® U having galvanically coated diamond segments with a blade width of 67 mm, thickness of 1.6 mm and a constant pitch of 30 mm.

Figure 2. Modified Kastoplate U3 bandsaw machine at tff, Universität Kassel

The principle of hydrostatic blade guide is shown in Fig. 3. The force exerted on a wall by a water jet according to Sigloch [4] is given in equation 1. Where F_{GS} is the reaction of the exerted force on the wall, ρ the density of the fluid (in this case water), $\dot{V}_D$ the volume flow rate per nozzle, w_D the speed of the jet coming out of the nozzle and A_D the cross-section area of the nozzle. In the system shown in Fig. 3, for the jet force to balance the passive force in the bandsaw blade while cutting, the reaction force F_{GS} should equal the sum jet force F_{Di}.

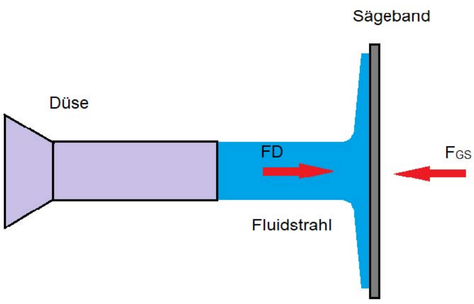


Figure 3. Simplified representation of the water jet on the bandsaw based on [4]

$$F_{GS} = \rho * \dot{V}_D * w_D = \rho * A_D * w_D^2 \tag{1}$$

In order to estimate the maximum force exerted by the band on the water jet (F_{GS}) (i.e. the passive force while cutting) cutting tests were performed on a single tooth linear cutting test rig at the sawing lab of tff. The linear test rig along with a single segment of the Diagrit bandsaw blade are shown in Figure 4. The tests were performed on 500 x 100 x 20 [mm] sized Carrara marble plates with a single segment of the Diagrit bandsaw blade. The linear cutting speed (v_c) was set at 150 m/min and feed per tooth (f_z) of 10 μm. Total quantity of stone cut amounted to a surface area of 250 cm^2 in the form of 10 separate grooves with each having a cut surface area of 25 cm^2. The average of the peak values of the passive force obtained while cutting the last groove was taken as the value to be used for calculation of the nozzle diameter. This was found to be 27 N which meant that with the total number of teeth in contact with the marble block on the bandsaw machine to be 10, the total passive force would amount to 270 N.

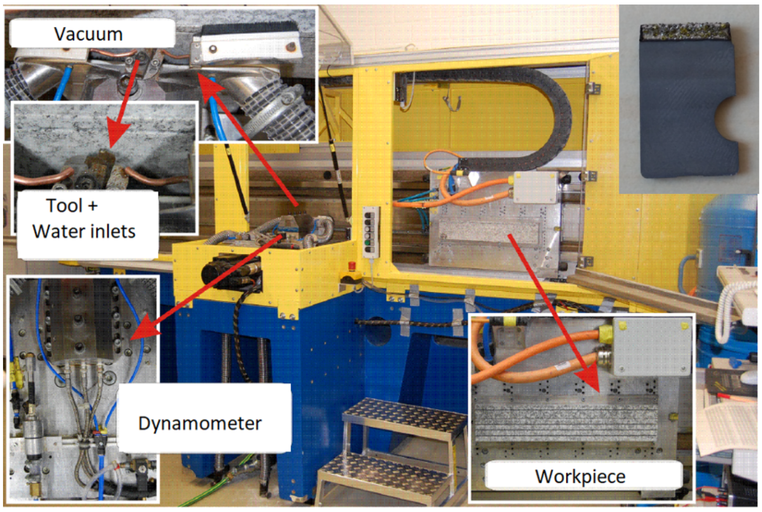


Figure 4. Linear test rig at tff [3] and wire-eroded single segment of galvanic diamond bandsaw blade

The hydrostatic band guides were designed in form of nozzle plates having 9 holes or nozzles. The plates were made out of stainless steel X5CNi18-10. The design of the guide system is shown in Figure 5. The water pump attached to the machine was a centrifugal pump with a maximum volume flow rate of 14 m^3/h and a maximum achievable pressure of 8 bar from the french manufacturer Wilo. The final design parameter i.e. the diameter of the individual nozzles was calculated based on the maximum force, volume flow rate of the pump and the number of nozzles as shown in equations 2 through 5.

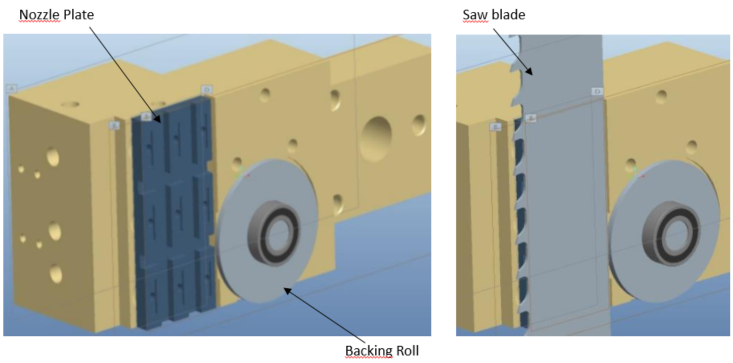


Figure 5. CAD Design of the hydrostatic blade guides

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2020 doi:10.20944/preprints202001.0257.v1

From the continuity equation of fluid dynamics, the mass flow rate ($\dot{m}$) is given as [4]:

$$\dot{m} = A * w * \rho, whereby A * w = \dot{V} \tag{2}$$

The volume flow rate per nozzle ($\dot{V}_D$) could be calculated from the maximum flow rate of the pump ($\dot{V}_{max}$) and the total number of nozzles as:

$$\dot{V}_D = \dot{V}_{max}/18 = 0.778 m^3/h \tag{3}$$

Substituting the value of $\dot{V}_D$ in equation 2 results in the mass flow rate per nozzle ($\dot{m}_D$) as being:

$$\dot{m}_D = 0.778 m^3/h * 1000 kg/m^3 = 778\,\mathrm{kg/h} \tag{4}$$

The required force per nozzle (F_D) could be calculated using the total required force (F_{max}) and total number of nozzles on either side of the band as:

$$F_D = F_{max}/9 = 270/9 = 30\,\mathrm{N} \tag{5}$$

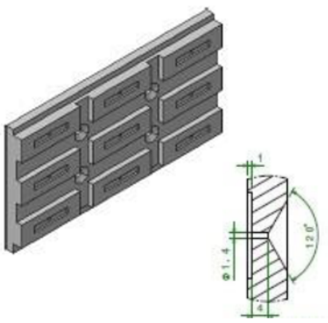
Substituting values from equation 4 and equation 5 in equation 2 and rearrangement results in flow speed per nozzle as:

$$w_D = F_D/\dot{m}_D = \frac{30N}{0.216\,\mathrm{kg/s}} = 140\,\mathrm{m/s} \tag{6}$$

Substituting this value again in equation 2 and rearranging gives the cross section area of the nozzle:

$$A_D = \dot{V}_D/w_D = \frac{0.778\,\mathrm{m}^3/\mathrm{s}}{140\,\mathrm{m/s}} = 1.54\,\mathrm{mm}^2 \tag{7}$$

giving the diameter of the nozzle to be 1.4 mm. The nozzle design based on this calculation is shown in Figure 6a and the hydrostatic guides mounted on the bandsaw machine are shown in Figure 6b. A fluid pocket has been designed to maintain a lubrication film between the band at the guides. This pocket helps to not only keep the guides clean but reduce or compensate any kind of friction build up through possible contact. The negative effects of the discontinous transition from nozzle to pocket were negligible when compared to the postive effects of the fluid pocket inclusion. It is important to point out that only the upper side of the bearing guides were replaced with hydrostatic guides. Replacement of the lower side of the guides required the machine bed to be heavily modified to allow the space for the larger hydrostatic guides to be installed and thus was not done.



(a)

(b)

Figure 6. (a) Nozzle plate with cross-section drawing of a single nozzle. (b) Mounted hydrostatic guide on the bandsaw

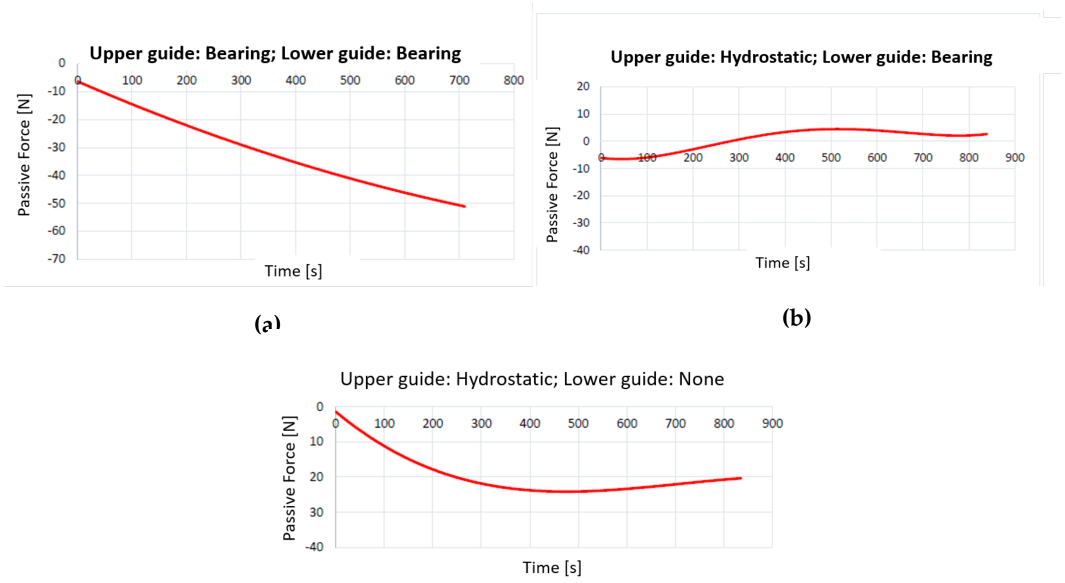
For a comparative study cutting tests on marble block were performed in three blade guide configurations. One, with both upper and lower blade guides being sealed bearings. Second, the upper bearing guide replaced with the hydrostatic system and third with upper hydrostatic guides and no lower guides. A distance of 0.2 mm was kept between the nozzle plates and the tensioned blade. Under each of these settings five repetitions of tests were performed and the results show the average of these five tests. The cutting speed (v_c) and feed rate were fixed at 150 m/min and feed rate (v_f) at 20 mm/min for all test runs. This translates to a tooth feed (f_z) of 4 μm, about half of that tested on the linear test rig. For the measurement of force a three component dynamometer of type Kistler 9257b was mounted on the bandsaw table in a stainless steel housing on which the stone block was clamped. In addition the surface roughness of the plates of marble cut were measured using FRT white light interferometer.

In the second part of the tests hydrostatic guides were used to tilt the band to either left or right while cutting. This was achieved by turning off the valves for two rows of nozzles on each side. The purpose of these tests was on one hand to straighten the cutting direction of the bandsaw in case it drifts to one side due to the presence of harder secondary phases in the stone or misalignment of the saw itself. The same technique could also be used to cut curved contours on a natural stone block.

3. Results and Discussion

3.1. Hydrostatic guides for straight cuts

The generated passive force (F_P) on the bandsaw blade while cutting results from the contact of the flank face of the tool with the machined surface. In our case the thin plates being cut gradually separate themselves from the stone block. Hence the only sideways force exerted on the blade is from the block side of the stone. Ideally the passive force should be relatively constant throughout the short cutting cycles employed during these tests. If the band drifts to either side of the straight line, it presses against the bandsaw guides resulting in an increase of the passive force. Figures 7a, 7b and 7c show the average passive force from five repetitions for each of the conditions as mentioned above.



(a) (b)

(c)

Figure 7. Average passive force progression from five repetitions with (a) sealed bearings as both upper and lower guides (b) hydrostatic upper guide and bearing lower guide (c) hydrostatic upper guide and no lower guide.

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2020 doi:10.20944/preprints202001.0257.v1

The surface roughness was measured using optical profilometer of the FRT GmbH, Germany on the samples cut of the plates cut under each setting. Only the plates cut in the first repetition (out of five) under each setting were used for topography analysis. 3D surface profiles obtained with the software Mark-3 for samples cut under the three band guide combinations are shown in figures 8a, 8b and 8c respectively. The mean roughness depth R_z according to the norm DIN 4786 was found to be 71.28 μm for the combination of both upper and lower guides being sealed bearings. When the upper guides were replaced with the hydrostatic guides, R_z was found to be 53.88 μm while R_z was found to be 95.65 μm when only the upper hydrostatic guides were in place. 3D surface profiles obtained with the software Mark-3 for samples cut under the three band guide combinations are shown in figures 8a, 8b and 8c respectively.

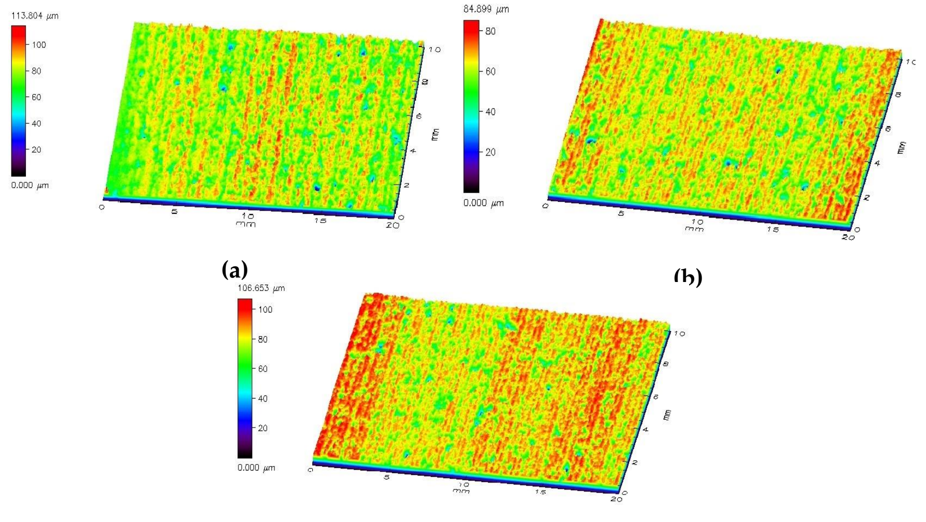


Figure 8. Average passive force progression from five repetitions with (a) sealed bearings as both upper and lower guides (b) hydrostatic upper guide and bearing lower guide (c) hydrostatic upper guide and no lower guide.

3.2. Band deflection with hydrostatic guides

The goal of these tests was to find out if the hydrostatic guides are able to deflect the bandsaw blade in case it drifts to either side while cutting. For this purpose two additional cutting test routines were performed (five repetitions each) whereby the band was deflected in both directions i.e. towards the block or towards the plate being cut. This was achieved by turning off the valves for two rows of the nozzle on both sides as shown in Figure 9. The actual deflection or tilt of the band could not be measured due to complications of nature of the cutting process particularly coolent flooding and film production. However, the passive forces observed during the deflection give a clear indirect indication of the band being deflected towards either side as shown in Figures 10a and 10b.

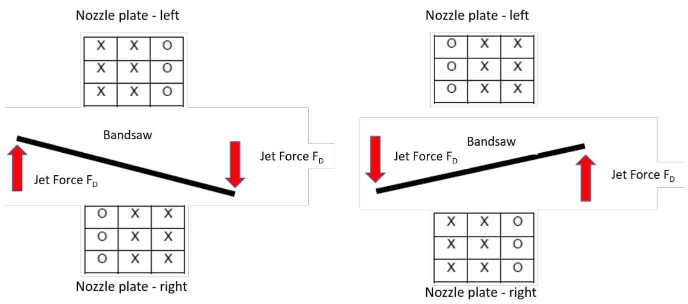
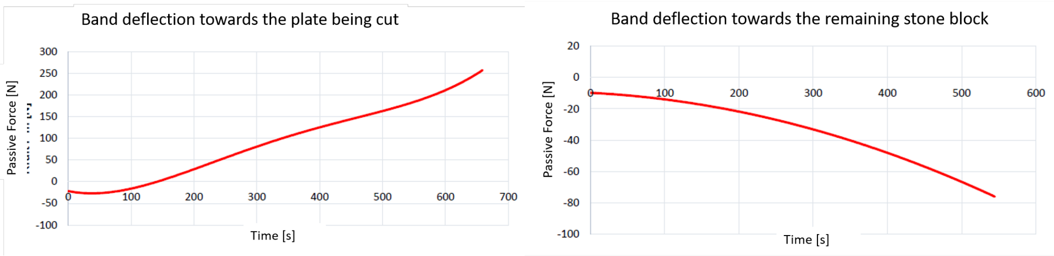


Figure 9. Nozzle plate configuration for band deflection towards the plate being cut (left) and towards the remaining stone block (right) whereby 0: open nozzle; X: closed nozzle

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 22 January 2020 doi:10.20944/preprints202001.0257.v1



(a) **(b)**

Figure 10. Average passive force for (a) band deflection towards the plate being cut (b) band deflection towards the remaining block of stone

The explanation, in the opinion of the authors, of the considerably higher passive force observed when deflecting the band towards the plate being cut is that the rear edge of the band presses against the solid stone block causing much higher forces. In comparison, the forces observed when the back edge presses against the plate being cut are much lower as the plate, having being partially cut already, is able to deform. This explanation also affirms the relatively greater deflection in the cut when the band was tilted towards the stone block compared to when it was tilted towards the plate.

The results of this preliminary study show that the hydrostatic blade guides, as designed for this work, are able to replace the block or bearing guides which are the state of the art in bandsawing technology. In fact, a comparison of Figures 6a and 6b show that the hydrostatic guides actually perform better than the bearing guides at keeping the cut straight and passive forces minimal and relatively constant. Although this study is a special case of cutting natural stone with a diamond bandsaw, the hydrostatic guides could in fact also be used for other cutting applications where bandsaw drift is a problem. As shown in Figures 10a and 10b, the simple nozzle configuration used here, is able to deflect the band in either direction in order to compensate for the drift. For this work, only the upper guides of the bandsaw were replaced with the hydrostatic system and further improvement could be obtained by having both upper and lower guides replaced with hydrostatic ones. Furthermore, a system with live measurement of blade drift and its automated compensation via dividual nozzle flow control are the future research opportunities.

4. Conclusions

In this work, an original experimental research was presented on the feasibility of hydrostatic blade guides as replacements for the bearing or block guides for bandsaws when cutting natural stones. The state of the art bearing guides cause abrasive wear the band from the sides when the abrasive stone particles settle on the rollers. Hydrostatic guide system as presented in this work, is a contactless blade guiding method that uses force of several water jets to keep the blade cutting in a straight line. For this investigation, cutting tests were performed on a marble block using a galvanic diamond coated bandsaw blade. Passive force progression during the cutting operation was used as the measured quantity to ascertain the effect of hydrostatic guides on the process. The main results were:

- With the upper blade guide replaced with hydrostatic guides, the observed passive force reduces to almost zero and remains relatively constant throughout the cutting cycle. In contrast when using bearing guides the passive force increases continuously until the end of the cutting cycle indicating that the band drifts to one side while cutting.
- Hydrostatic guides are also able to compensate for the blade drift by turning nozzles on and off in certain configurations (see Fig. 9) and tilt the blade in the opposite direction to the drift resulting in a straight cut.

Author Contributions: A.A.: conceptualization, methodology, analysis, original draft preparation; J.K.: Experimental work, analysis; K.K.: writing – review and editing, S.B.: supervision, funding acquisition.

 doi:10.20944/preprints202001.0257.v1

Funding: This research was funded by Bundesministerium für Bildung und Forschung (BMBF) (Federal ministry of education and research, Germany) grant number 02P14A060.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Böhm, S., Scherm, W., Reichenbächer, H. Steinbearbeitung mit geometrisch bestimmter Schneide aus PKD. *Diamant Hochleistungswerkzeuge* **2011**, *3*, 32–35.
2. Böhm, S., Scherm, W., Schwarte, S., Heise, C. Bearbeitung von Stahlbeton mit geometrisch bistimmter Schneide aus PKD. *Diamant Hochleistungswerkzeuge* **2012**, *2*, 28–35.
3. Reichenbächer, H. *Trennen mineralischer Werkstoffe mit geometrisch bestimmten Schneiden*; Kassel university press GmbH: Kassel, Germany, 2010.
4. Sigloch, Herbert. *Technische Fluidmechanik*; Springer Vieweg: Berlin-Heidelberg, 2017.