

# Adaptronic Chatter Damping System for Deep Hole Drilling

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## Abstract

Single lip deep hole drilling is a process for machining bore holes with a high length to diameter ratio. It is applied for drillings with up to 40 mm diameter. The cooling lubricant supply internally through the tool and the chip removal via an external straight chip flute is characteristic for this method.

In order to enhance process productivity it is necessary to increase the process parameter values. In the case of single lip deep hole drilling these parameters are feed and cutting speed. However, when increasing these parameter values the process can be subjected to dynamic instabilities in form of chatter vibrations of the tool. Chatter occurs due to the long and slender tool shape, which is very susceptible to torsional deformation. The development of a chatter suppression system, implemented as a tool holder between spindle and tool, offers a possible solution for increasing the process parameter values without the negative side effect of vibrations.

## Keywords:

Adaptronic machine device, chatter suppression, deep hole drilling

## 1 INTRODUCTION

At the Department for Machining Technology (ISF) chatter vibrations in different deep hole drilling processes are investigated. This paper focuses on the conception and the development of an adaptive damper for single lip drilling.

Characteristic for single lip drilling is the high surface quality of the machined bore holes. Due to the chatter vibration the cutting edge is affected by a dynamic load, that leads to loss of tool life time and production quality. Therefore, an adaptronic, that means self sensing and acting, damping device is to be developed for reduction of chatter and its negative effects [1-4].

There are generally three approaches for damping systems. Vibrations can either be damped passively, actively or adaptive-passively. In this specific case the most promising approach is an adaptive-passive damping system. The sophisticated tool holder concept is based on a viscous clutch, filled with a magneto-rheological fluid (MRF) [5]. This fluid is adjustable in its rheological properties by a magnetic field. It consists of a basic silicon oil with dispersed polarized solid particles. In case of magnetic fields going through the fluid the particles align along the flux lines and build chains that influence the viscosity of the dispersion. The range of the viscosity can be adjusted from liquid to solid. In case of the adaptronic tool holder the MRF is located within a gap between the power input flange and the power output flange. If a magnetic field is applied to the clutch its power transmission properties can be varied by the intensity of the field. The occurring chatter will be damped by the spring damping system of the elastomer like behavior of the MRF in the solid body modus. The normal operating condition of the MRF is the solid condition. In case of vibrations the viscosity will be decreased and the chatter will be damped.

Based on this concept, a design has been developed and is being built. Additionally, to complete the adaptive system, the tool holder has to be fitted with two acceleration sensors to detect the occurrence of chatter. Furthermore a control device for calculating the strength of

the magnetic field against the detected chatter frequency has to be implemented. Currently the control device is being programmed.

## 2 DETERMINATION OF REQUIREMENTS

First, process knowledge had to be obtained to define the requirements the device has to fulfill. Therefore, both experimental and virtual investigations with the help of FEA were carried out. The experimental investigations were performed on a three axis machining centre of type IXION by Maschinenfabrik Otto Häfner GmbH & Co KG. A special feature of this machine is the drill arm which positions the drill bush relative to the work piece (fig. 1). In order to protect the tool against bending, there are stationary supports along the tool shaft.

The vibrations were detected by a rotation dynamometer and by an accelerometer as torsional chatter. The dynamometer is limited in its frequency range the acceleration sensor signal is therefore more reliable. The acceleration sensor was placed on the drill arm, so that it was assured that the structure born sound will be detected.

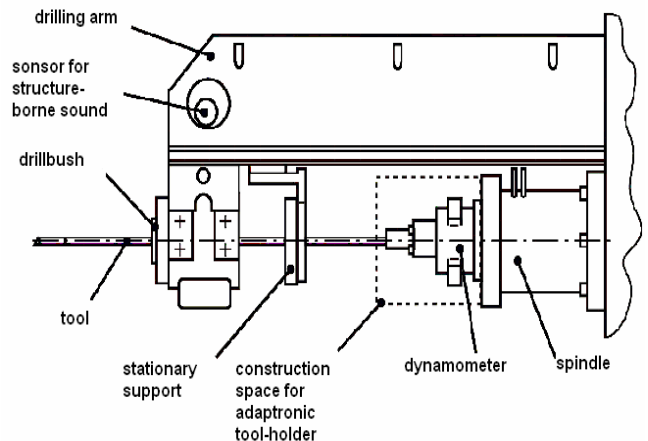


Fig. 1: Sketch of the experimental setup

During the experiments different tool diameters and lengths were analyzed. Additionally, different work piece materials were machined. The process parameters feed and cutting speed were varied, too [6,7]. The experiments showed clearly, that the feed was the major parameter to influence the occurrence of chatter vibrations. With higher feed values the system began to be affected by dynamic instabilities that lead to chatter [8-10]. The recorded chatter signal was analyzed by applying a FFT, to calculate the major chatter frequencies. These frequencies were shown to be the first torsional eigenfrequencies of the applied tools. Additionally, there were spectral peaks to be seen that were odd multiples of the first eigenfrequency. The highest values of torsional chatter frequencies determined amounted up to 3 KHz for the applied tools.

With the help of FEA the experimental results were confirmed. A modal analysis as well as a frequency response analysis has been performed. The FEA is a very helpful tool to acquire process knowledge because of the inaccessibility of the cutting zone. The maximum drill angle was computed as up to 25 degree.

These are the boundary conditions for the development of the adaptronic damping device. Furthermore the adaptronic device must be retrofit in existing machining concepts as an autonomous machine device. It must also be applicable for different tool diameters and lengths.

### 3 POSSIBLE DAMPING APPROACHES

In general three different damping methods are suitable for the damping, actively, passively and adaptive-passively. Hauger [11] already proved that damping is possible when the torque transmission is complemented by an interface for relative movement, where the tool shaft is clamped. The machine spindle is rigid in comparison to the small and slender tool shaft. For torsional vibration the tool clamping in the spindle can be assumed as a nodal point, where no influence can be exerted. Therefore, an interrupt for the torque has to be integrated to create an adjustment travel. The feed rate and its force are to be transmitted directly.

The first option investigated was the active damping system. In an active system the chatter suppression is carried out by a phase delayed counter vibration. Because of the delay, the self excited vibration will be neutralized. For this purpose it would be necessary to develop a very fast control device and an actuator capable of high frequencies.

Piezo actuators have this frequency range but only a very small adjustment travel. Because of this, an adaptronic device based on piezo actuators will not work reliable. Other actuators with higher adjustment travels do not show such fast response times. Additionally, there are often constructional difficulties when integrating such actuators into an adaptronic tool holder device, because of the limited construction space and the need of rotational symmetry.

Another difficulty is the energy supply for the actuators. Especially piezo actuators consume much energy, which is difficult to supply to a revolving system due to the high voltage required. These are facts that make an active system less promising than other concepts.

The second approach is the passive damping method. Hauger already performed investigations, and the conclusion was, that passive damping of torsional vibrations leads to higher process parameter values without occurrence of chatter. Unfortunately the passive damping mechanism must be adjusted specific for every tool. Another restriction was that especially bigger tool diameter couldn't be equipped with the passive damper because of the absence of adequate construction space.

The third approach is an adaptive passive damping system in which a passive damper is made adjustable and the adjustment device is self sensing. This will fulfill the requirement that the design of the system must allow it to be retrofit to existing machining systems and it must be applicable to different tool dimensions (fig. 2).

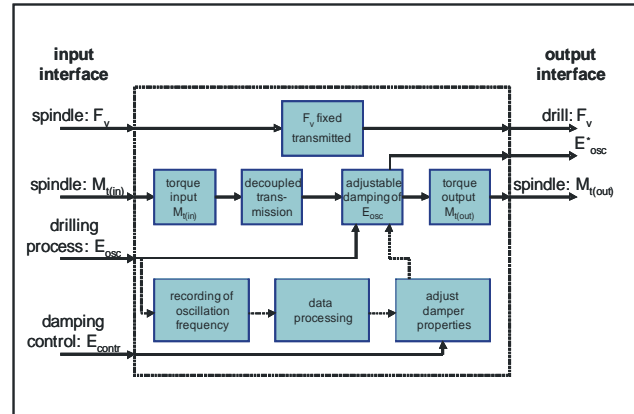


Fig. 2: Plan of the adaptive-passive approach

In order to design an adaptive passive damping device different possibilities have been investigated. The most promising one was a kind of viscous clutch filled with a magneto-rheological fluid (MRF). The fluid consists of a basic oil, in most cases a synthetic silicon oil. In this oil metallic particles are dispersed. The length of these particles is only a few micrometers. The behaviour of the particles is influenceable by a magnetic field. As soon as a magnetic flux line passes through the fluid the metallic particles align to a chain in direction of the lines (fig 3).

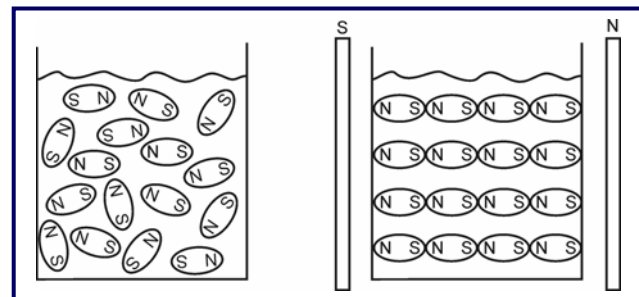


Fig. 3: Behavior of the metallic particles under influence of a magnetic field

By building these chains of particles, the viscosity of the fluid varies. The stronger the magnetic flux lines are, the stronger the chains become. The strength and number of the particles' chains determine the viscosity of the fluid, because the oil is more and more immovable between the chains. The range of adjustment of the viscosity of the MRF is between fluid like the basic oil and solid like an elastomer. In this solid mode the MRF is a spring damper system influenceable by the magnetic field.

Power input and power output are separated by gaps filled with MRF. The transmission of the torque is accomplished by the particle chains in the fluid. Because of the solid mode in normal process behavior the power input and the power output are connected by the particle chains. The surface of the housing and the surface of the solid mode MRF are stuck together.

This is the initial situation for the load transmission during the process. As soon as chatter occurs the magnetic field will be reduced, so that the MRF becomes ductile and the energy of the vibration can be absorbed.

#### 4 DESIGN OF THE PROSPECTED DAMPING DEVICE

Thereon the dimensioning of the adaptronic device was to be accomplished. During the experimental investigations different tool diameters, work piece materials and process parameter values were applied. The requirements for the dimensioning are always the maximum value detected during the tests. The maximum torque to be transmitted was 25 Nm. It occurred with application of the biggest tool diameter of 15 mm.

Another boundary condition is the maximum construction space limited by the machine peripheries because of the drill arm positioned above the tool. The distance between drill arm and tool centre line amounts to 150 mm. This means that the maximum diameter of the adaptronic device is up to 300 mm including the energy supply.

The general design of the clutch was the socket design as Lampe [12] classified in his dissertation as the coaxial alignment (fig 4). This design was chosen, because of the compactness needed. The arrangement of the gaps for the MRF parallel to the centerline allows a big transmission face and small diameter cross section. Another advantage is the nearly constant shear load across the whole cross section. The transmission face is enlarged additionally due to the fact, that the output flange is surrounded by the MRF on both sides. The four gaps filled with fluid ensure the possibility to transmit high levels of torque. The length of each of the four gaps is 35 mm, the thickness is 3 mm. The outer gaps have a middle diameter of 42 mm, the inner ones of 35 mm.

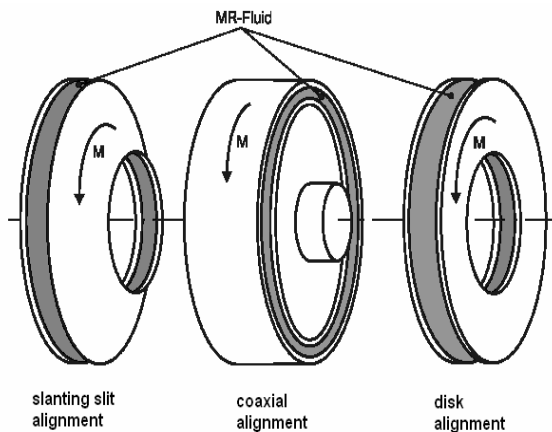


Fig. 4: possible gap arrangements [12]

In order to determine how strong the magnetic field has to be to transmit the required torque, not only the dimensions are to be known, but also the dynamic shear rate of the MRF-fluid.

The dynamic shear rate depends on the fluid and its metallic particles. This constant is difficult to measure but the static shear rate is easier to detect. Its value is always a little smaller, so that it is possible to approximate the dynamic shear rate with the static one. The fluid taken for the dimensioning was the Versa Flow 100 by the Lord Corporation, Cary, North Carolina, USA. For the specification mentioned above, the required strength of the magnetic field is 0.116 Tesla to transmit 25 Nm.

To ensure that the gaps are constantly and consistently passed through by the magnetic flux lines, two magnetic flux coils are positioned at the sides of the gaps. This means, that each coil supplies two gaps with the magnetic field. As to be seen in fig. 5 the thickness of the coil accords with the height of the two gaps and the thickness of the power output rotor. With a width of 11 mm, the cross section of the magnetic coils amounts  $110 \text{ mm}^2$ . The cross section for each electrical conductor will amount to  $1 \text{ mm}^2$ . Following standard calculations the determined number of windings is 100. For the required magnetic field

of 0.116 Tesla, the energy supply of the coil with this dimension is 3.09 Ampere at 1.235 Volts.

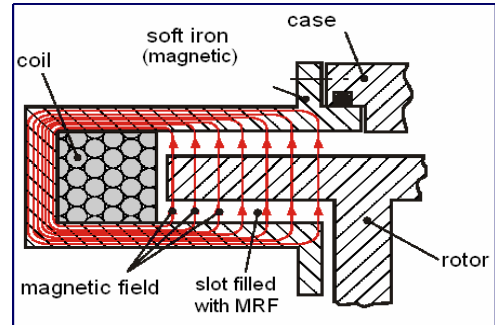


Fig. 5: Travel of the magnetic flux lines within the construction

The electrical energy supply for the magnetic coils will be transmitted by four collector rings. They run in an open system. The voltage is rather small, so that an open system does not entail any problems. The magnetic coils are made of copper, surrounded by a special lacquer. After winding the coil, it will be warmed up, and the lacquer will glue the windings together.

The material of the housing has to be highly magneto conductive. The higher the permeability of the material is, the smaller the loss will be. For the construction, the sintered metallic material 1321 by SMP Sintermetalle Prometheus, Graben-Neudorf, Germany is applied. It is the best compromise between permeability and machinability. Because of its high permeability, the hysteresis of the components made of this material will be very small [13]. That leads to short response times for the whole system. The material of the power output flange is 1321 too, because of the magnetic flux line going through this component as well.

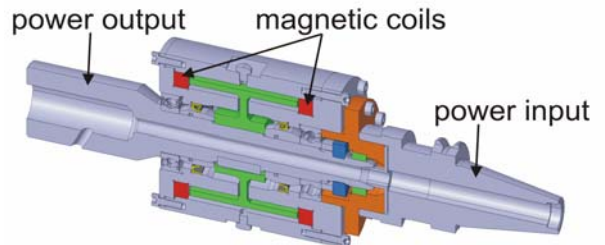


Fig. 6: Cross section view of the entire assembly

In fig. 6 is to be seen the cross section view of the entire assembly. The length of the construction amounts 370 mm, the diameter 112 mm. Due to the steep angle taper clamping it is retrofit to existing machining centres.

The transferable torque depends on the strength of the actual magnetic field. The MRF to be used is the Rheonetic Fluid MRF-132LD produced by the Lord Corporation, because of its higher shear rate, that leads to higher torque transmission.

The LORD MRF 132DG is a hydro carbon based magnetorheological fluid formulated for general use in controllable energy dissipating applications such as shock absorbers, dampers and brakes. It consists of micron sized magnetizable particles with a weight percentage of about 81. Its dynamic yield strength allows a wide range of controllability because of the high yield strength under presence of a magnetic field and the low yield strength when the magnetic field is missing [14]. Since the adaptronic damping device is operating with the MRF in the solid mode, there is no separation of particles expected. Although when separation takes place after a longer downtime, a redispersion is produced by the revolving system [15].

Another advantage of this fluid is its high resistance against temperature variation. Furthermore, because of the cold lubrication running through the device, the MRF is not subjected by an undesired temperature variation. Moreover, because of the non abrasiveness of the particles there is no danger of wear for the surrounding housing elements or magnetic field coils.

## 5 PERIPHERY

The electrical energy is supplied by computer controlled amplifiers. The appropriate voltage is computed by a programmable software tool. The background information needed for defining the appropriate voltage is deposit in a mapping which is to be determined in experimental tests.

For the control device of the adaptronic tool holder, the incoming signal for chatter detection will be detected by acceleration sensors. Two of them will be applied at the tip of the tool holder, where the tool shaft is positioned. During the experimental investigations, the structure borne sound, detected by acceleration sensors was shown to be a reliable signal for chatter detection. Two sensors are necessary for the detection of torsional and not bending vibrations. They have to be applied at an angle of 90°.

The transmission of the signal detected by the acceleration sensors is conducted by a telemetric system. Due to this it is possible to transfer the signal without losses of information. The entire periphery is to be seen in fig. 7.

After detection of chatter vibration, the signal has to be processed by the control device in order to compute the appropriate magnetic coil voltage. Therefore a mapping has to be determined to receive knowledge about the damping properties in comparison to the actual strength of the magnetic field. This is necessary for the control device to adjust the appropriate voltage for the current process situation.

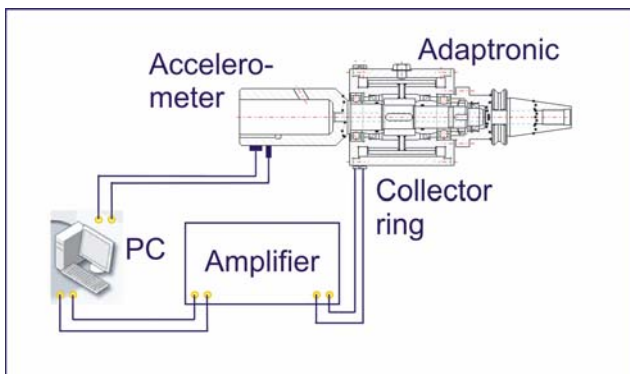


Fig. 7: Periphery of the adaptronic damping device

## 6 SUMMARY AND OUTLOOK

The occurrence of chatter mainly depends on the feed during the process. Chatter in deep hole drilling is a self excited torsional vibration of the tool and its frequency depends on the eigenfrequency of the applied tool. Due to the requirement that different tool geometries must be applicable, an adaptive chatter damping tool holder device has to be developed.

Different damping approaches were considered during the development. The adaptive passive damping approach based on the magnetorheological effect was the most promising one. The design of the adaptronic tool holder is based on the concept of viscous clutches. Due to the MRF in the gaps between power input and power output the transmission behaviour of the adaptronic device is adjustable. For chatter energy absorption it can be set from hard to softer.

Further investigation will focus on the integration of the

control device into the adaptronic tool holder. This leads to more compactness to meet the requirement of the device having to be retrofitted.

Furthermore applications for other processes are conceivable. Especially extra long twist drills are becoming more and more common and are also affected by torsional vibrations. These tools have the same requirements as the single lip drills. They need an internal supply with lubrication, a constant feed rate and an influenceable torque transmission. Therefore another tool clamping has to be developed for application in the adaptronic tool holder concept.

## 7 ACKNOWLEDGMENTS

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