Leibniz-Institut für Polymerforschung Dresden

NUMERICAL INVESTIGATION OF THE VIBRATION BEHAVIOR OF A COMPOSITE DRILL TUBE

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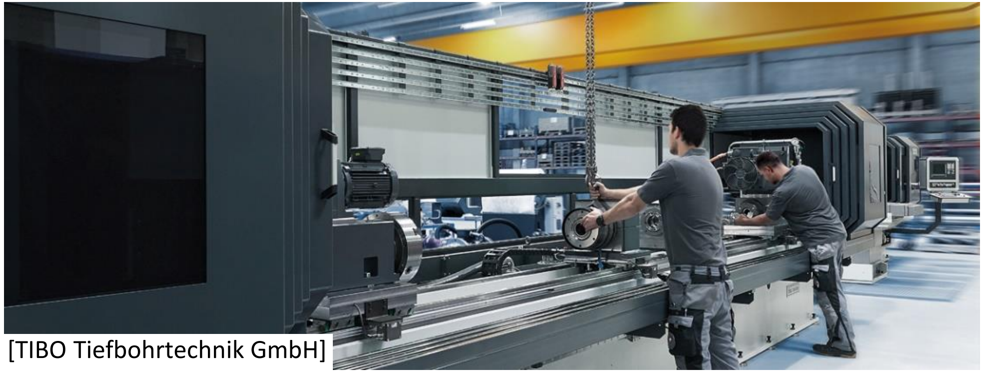
BTA Deep Hole Drilling


[TIBO Tiefbohrtechnik GmbH]


[ISF]

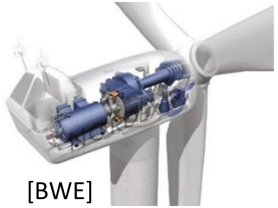
Typical applications

Plastic processing


[Techpla]

Double twin-screw extruder barrel

Renewable energy


[BWE]


[europages]

Rotor and generator shafts

Lightweight design


[BGTB]

Aircraft landing legs

Chemical industry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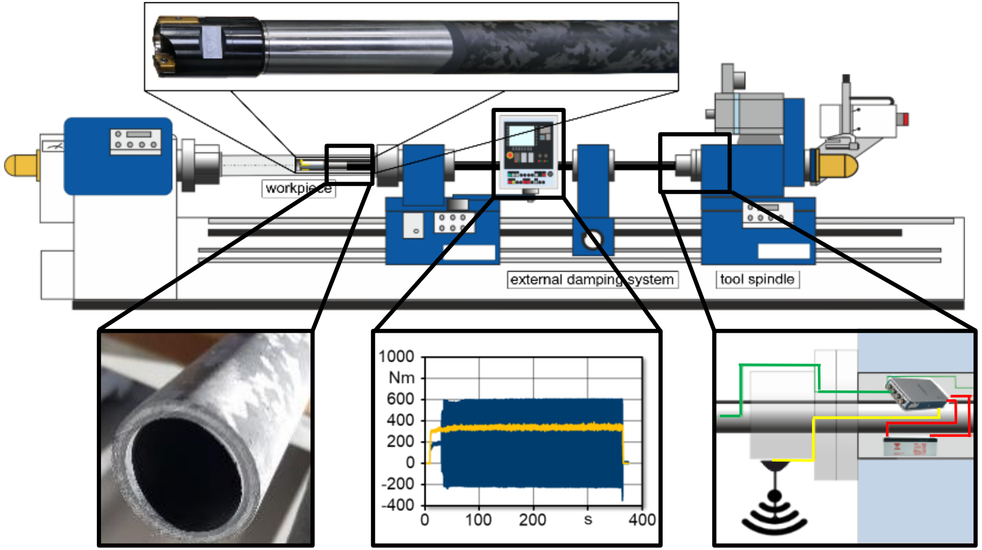
High-pressure pipes

Composite Drill Tubes for BTA Deep Hole Drilling



Composite drill tube

Drilling torque measurement

Sensors, telemetry

Aim of the project:

- Vibration-damping
- Weight reduction
- Structure-integrated sensors
- Hybrid connection concept

Design and Manufacture of the Composite Drill Tube

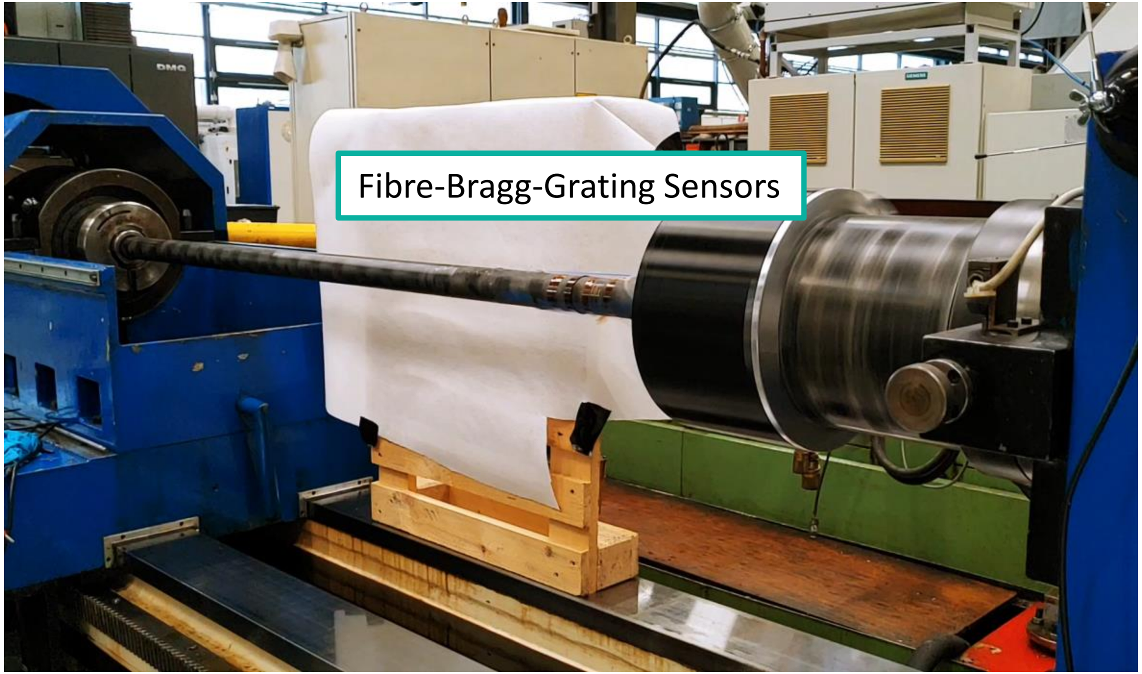
Geometry:
d_i = 40 mm, d_a = 51 mm, l = 2650 mm

Laminate structure:
$[\pm 6_2^{CF1}/\pm 45_2^{GF}/\pm 45_2^{CF1}]$

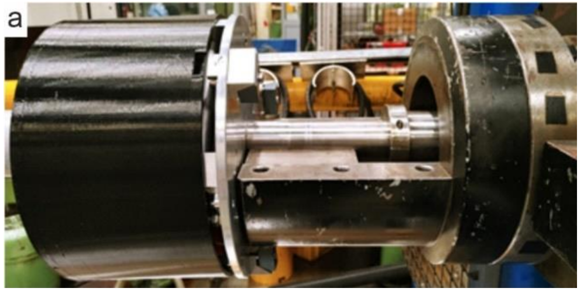
Name	Material	Stiffness [GPa]
CF1	STS40 F13, 24K, 1600 tex (Toho Tenax)	240
CF2	Dialead K63712, 12K, 2000 tex (Mitsubishi Chemical)	640
GF	SE1200, 2400 tex (Owens Corning)	82
Matrix	Epikote MGS RIMR 935 with Epikure MGS RIMH 937 (Hexion)	-

Bonded steel adapters with drill head

Process Parallel Vibration Measurement



Video of the rotating drill tube with sensors in drilling test



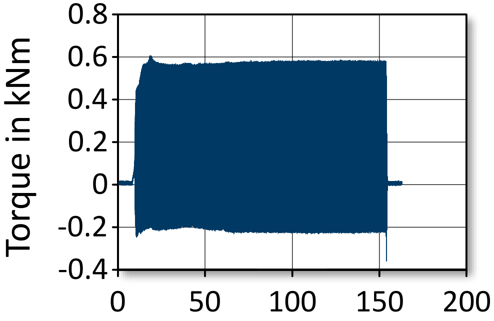
Mounting the platform and the drill tube on the drill chuck

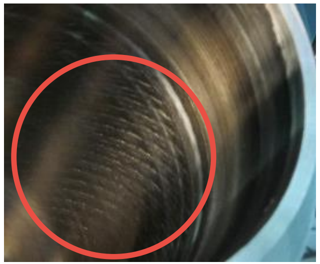
Platform with interrogator (red) and two measuring amplifiers (white)

More Information: https://doi.org/10.1016/j.procir.2022.10.060

Results of the Drilling Tests

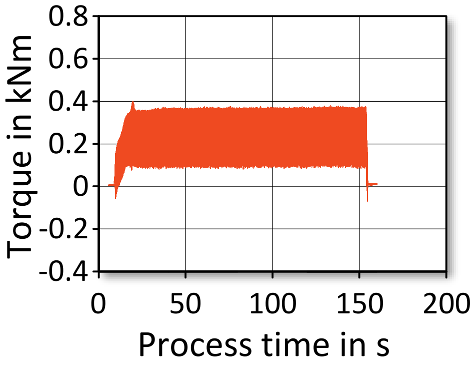
Steel
drill tube



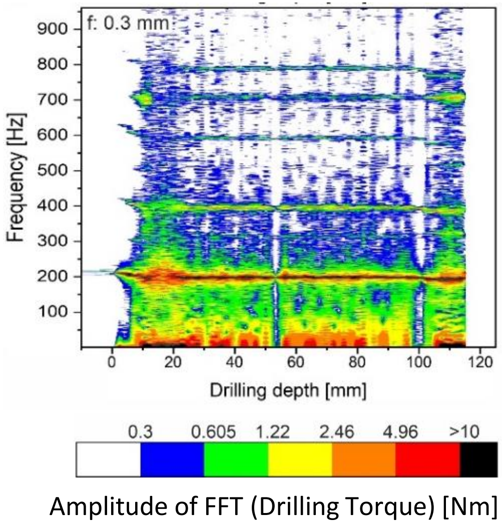


Chatter marks caused
by torsional vibrations

Composite
drill tube



FFT analysis over drilling depth



Process parallel vibration analysis

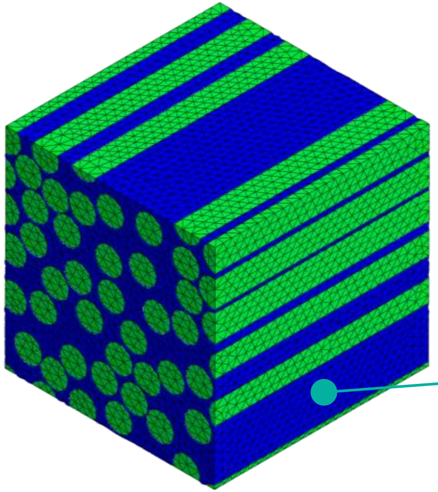
Improved surface quality

Vibration damping due to composite use

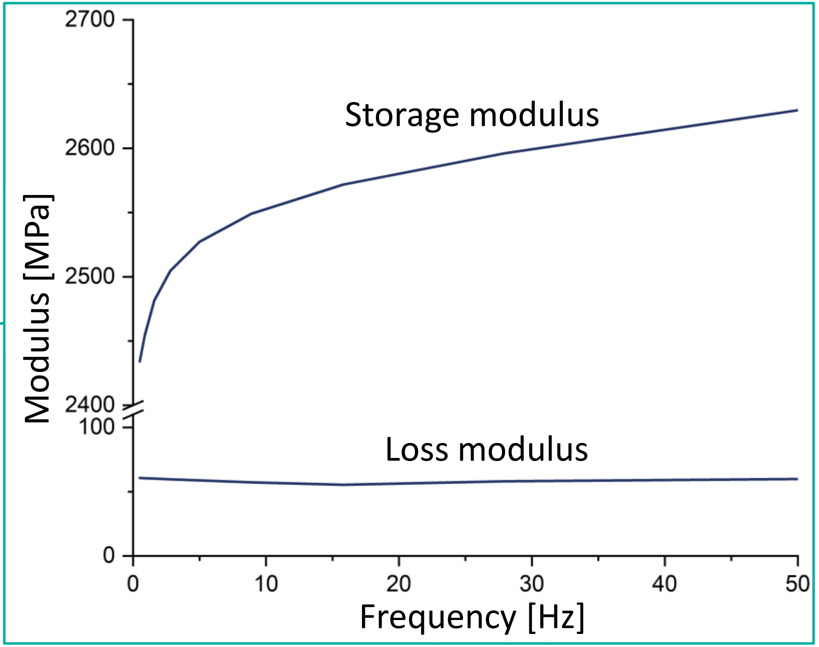
More Information: https://doi.org/10.1016/j.procir.2022.10.060

How can the material damping of the composite drill tube be simulated?

Model Approach



DMA measurement on epoxy resin at 20°C

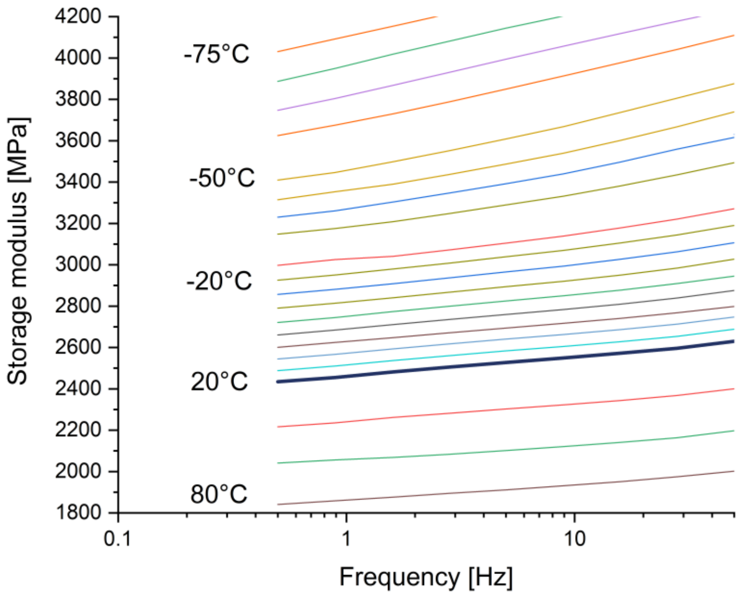


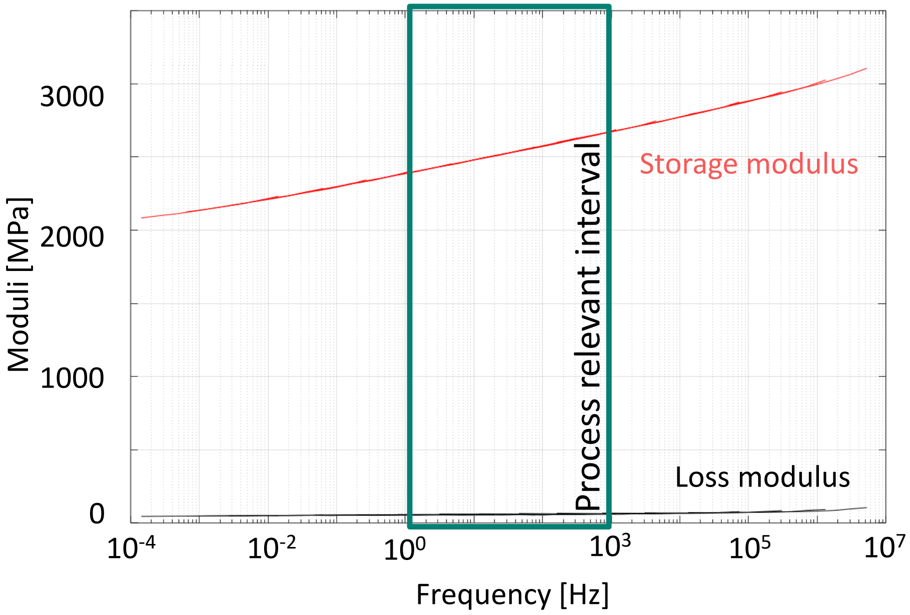
Measured natural frequency of the composite drill tube: **218 Hz**

Directional material damping

- Fibers: no damping (model)
- Epoxy resin: damping (visco-elastic)

Time-Temperature Superposition





DMA measurement:

- NETZSCH EPLEXOR 2000N
- Temperature-Frequency-Sweep
- 0.5 to 50 Hz; -80 to 90 °C

Approximation by Prony series:

$$E(t) = E_0\left(1 - \sum_{i=1}^{N} g_i\left(1 - e^{-\frac{t}{\tau_i}}\right)\right)$$

Mixing the Matrix and Fiber Properties in an Abaqus User-Material

$$E_1' = E_{1f}\,\varphi + E_m\,(1-\varphi)$$

$$E_1'' = \frac{E_m}{(1-\varphi)}$$

Fiber properties:
non time-dependent

Matrix properties:
time-dependent

$$E(t) = E_0\left(1-\sum_{i=1}^{N} g_i\left(1-e^{-\frac{t}{\tau_i}}\right)\right)$$

Storage Modulus

$$E_2' = \frac{E_m}{1-\nu_m^2}\,\frac{1+0.85\,\varphi^2}{(1-\varphi)^{1.25}+\frac{E_m}{(1-\nu_m^2)\,E_{2f}}\,\varphi}$$

$$G_{12}' = G_m\,\frac{1+0.4\,\varphi^{0.5}}{(1-\varphi)^{1.45}+\frac{G_m}{G_{12f}}\,\varphi}$$

$$\nu_{12}' = \varphi\,\nu_{12f} + (1-\varphi)\,\nu_m \qquad \nu_{21}' = \nu_{12}'\,\frac{E_2'}{E_1'}$$

Loss Modulus

$$E_2'' = \frac{E_m}{(1-\varphi)}$$

$$G_{12}'' = \frac{G_m}{(1-\varphi)}$$

$$\nu_{12}'' = \varphi\,\nu_{12f} + (1-\varphi)\,\nu_m \qquad \nu_{21}'' = \nu_{12}''\,\frac{E_2''}{E_1''}$$

H. Schürmann “Konstruieren mit Faser-Kunststoff-Verbunden”, Springer-Verlag Berlin, 2007, https://doi.org/10.1007/978-3-540-72190-1

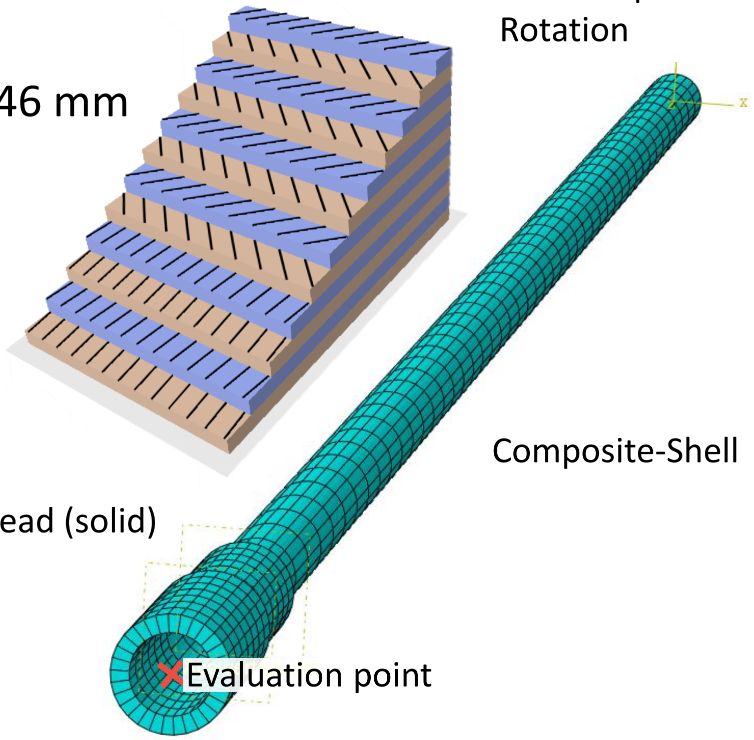
Modeling of the Drill Tube in Abaqus

Plies | Offset | Shell Parameters | Display

☐ Make calculated sections symmetric

		Ply Name	Region	Material	Thickness	CSYS	Rotation Angle	Integration Points
1	✔	Ply-1	(Picked)	CF1_UMAT	0.46	<Layup>	6	3
2	✔	Ply-2	(Picked)	CF1_UMAT	0.46	<Layup>	-6	3
3	✔	Ply-3	(Picked)	CF1_UMAT	0.46	<Layup>	6	3
4	✔	Ply-4	(Picked)	CF1_UMAT	0.46	<Layup>	-6	3
5	✔	Ply-5	(Picked)	GF_UMAT	0.46	<Layup>	45	3
6	✔	Ply-6	(Picked)	GF_UMAT	0.46	<Layup>	-45	3
7	✔	Ply-7	(Picked)	GF_UMAT	0.46	<Layup>	45	3
8	✔	Ply-8	(Picked)	GF_UMAT	0.46	<Layup>	-45	3
9	✔	Ply-9	(Picked)	CF1_UMAT	0.46	<Layup>	45	3
10	✔	Ply-10	(Picked)	CF1_UMAT	0.46	<Layup>	-45	3
11	✔	Ply-11	(Picked)	CF1_UMAT	0.46	<Layup>	45	3
12	✔	Ply-12	(Picked)	CF1_UMAT	0.46	<Layup>	-45	3

t=0.46 mm



Fixed Displacement/ Rotation

Composite-Shell

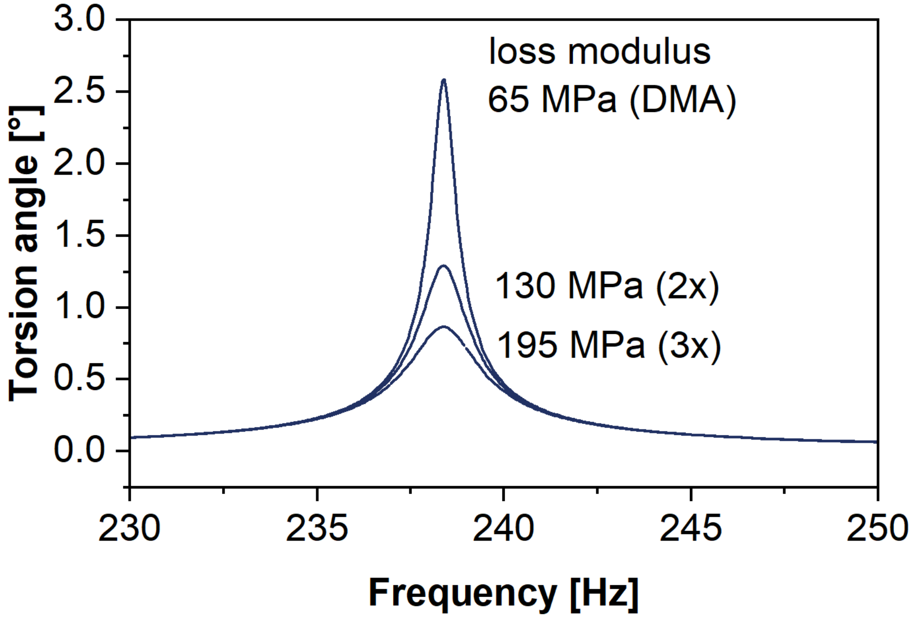
Steel drill head (solid)

Evaluation point

Torque:
Static: 300 Nm
Dynamic: 0.4 Nm

Drill head can rotate and shift in Z-direction

Results: Influence of the Loss Modulus



Variation of the loss modulus

- Fiber volume content: 55%

Laminate structure:

$[\pm 6_2^{CF1}/\pm 45_2^{GF}/\pm 45_2^{CF1}]$

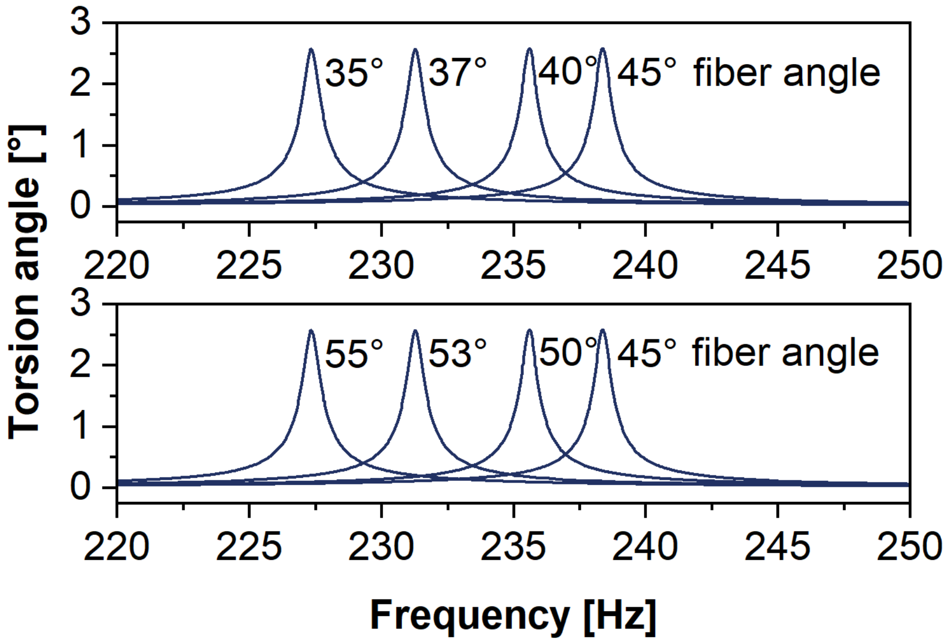
Matrix material has great influence on vibration amplitude.

Results: Influence of the Fiber Angle

Variation of the fiber angle

- Variation of ±45° layers
- ±6° layers for axial load not varied

Laminate structure:
$[\pm 6_2^{CF1}/\pm 45_2^{GF}/\pm 45_2^{CF1}]$



Fiber angle influences natural frequency but not vibration amplitude.

Results: Influence of the Fiber Material

Variation of the fiber material

- Same fiber material X in all layers
- Fiber volume content: 55%

Laminate structure:

$[\pm 6_2^X / \pm 45_2^X / \pm 45_2^X]$

Name	Material	Stiffness [GPa]
CF1	STS40 F13, 24K, 1600 tex (Toho Tenax)	240
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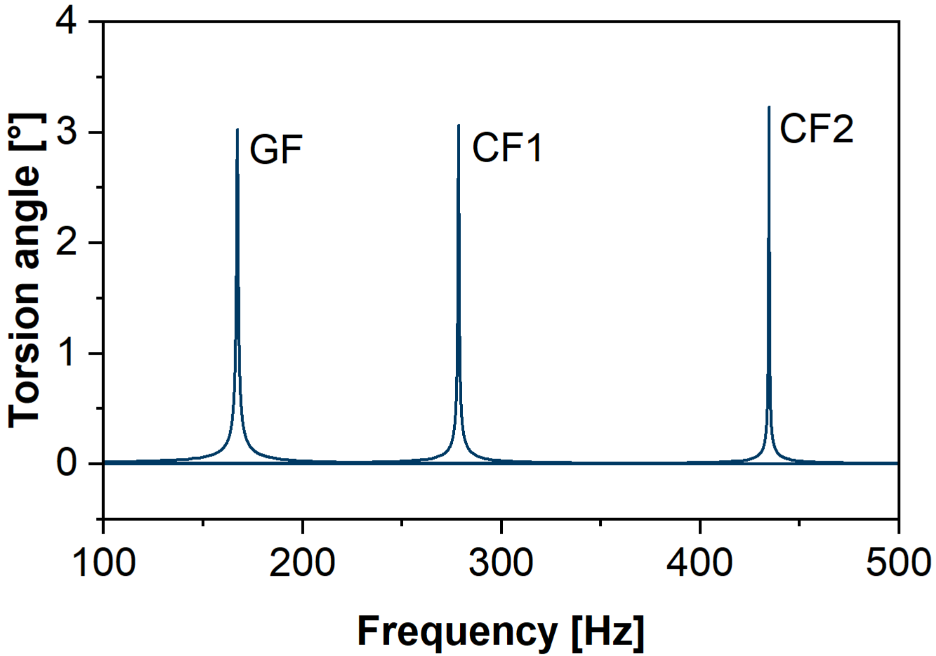
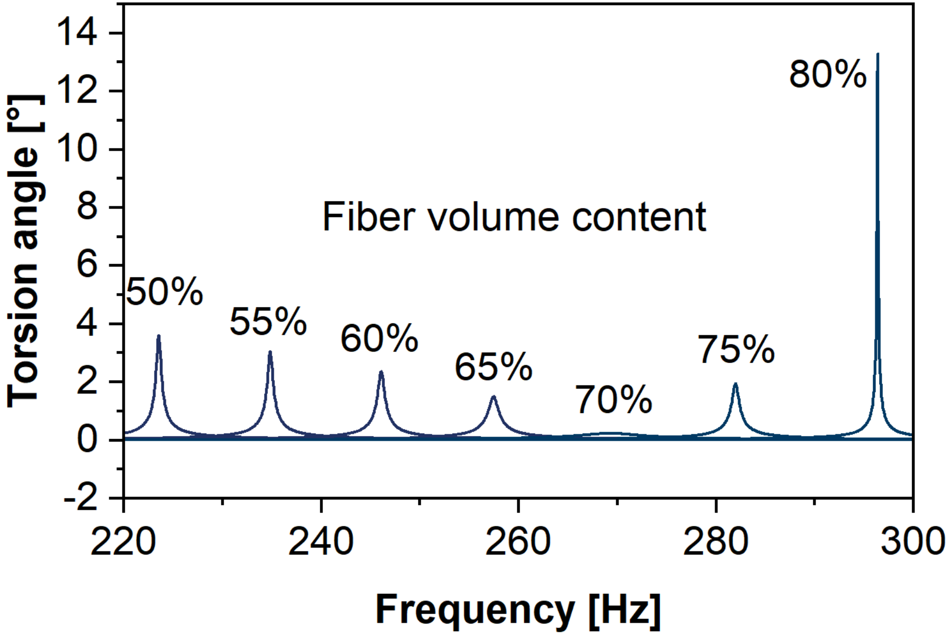


Natural frequencies depend significantly on the material. Vibration amplitude is almost the same.

Results: Influence of the Fiber Volume Content

Variation of the fiber volume content

Laminate structure:
$[\pm 6_2^{CF1}/\pm 45_2^{GF}/\pm 45_2^{CF1}]$



Increasing the fiber volume fraction from 50 % to 65 % halves the vibration amplitude.

Conclusion and Outlook

- The use of composite in deep hole drilling tools significantly reduces vibrations
- Model approach for vibration amplitude prediction presented
- Matrix material and fiber volume content influence vibration amplitude
- Fiber material and fiber orientation primarily influence the natural frequency
- Model approach must be validated experimentally
- Comparison of the numerical experiments with real drilling tests is still pending

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Thank you for your attention!

Project partners:

Fraunhofer IZFP

ISF Institut für Spanende Fertigung

BGTB GmbH Beratende Gesellschaft für Tiefbohr- und Zerspanungstechnik

carbovation MURTFELDT COMPOSITES

KAISER Maschinenbau

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