Optimisation of the longitudinal-torsional output of a half-wavelength Langevin transducer

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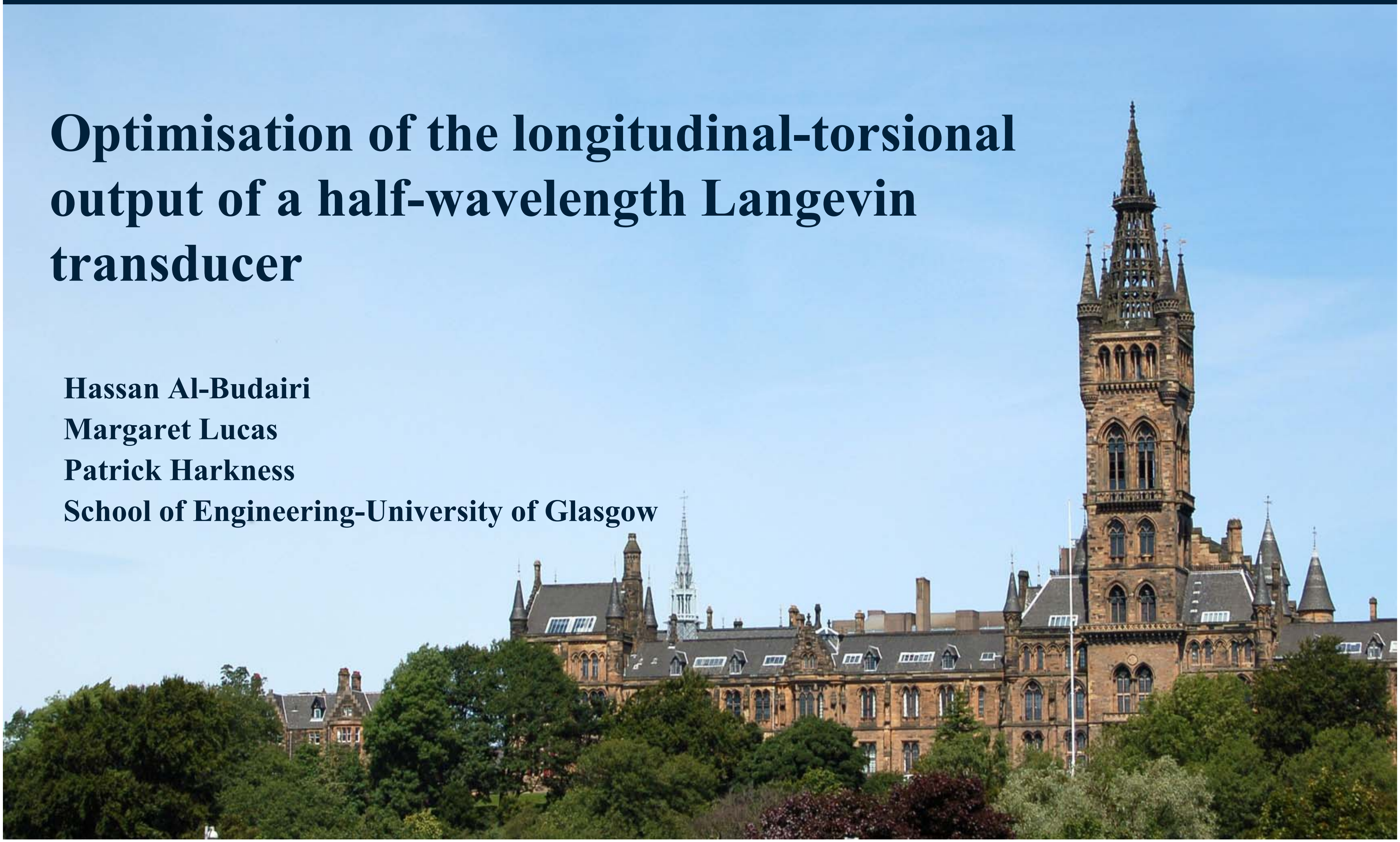


Outline

-LT vibration.

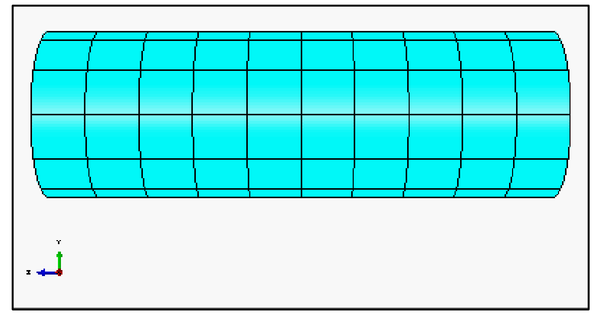
-Applications.

-Method of producing LT vibration.

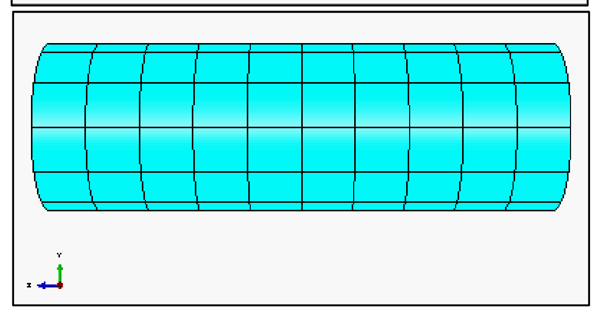
- New method, features and conclusion.

Longitudinal-torsional shape of motion (LT):

- **Longitudinal mode (L)**



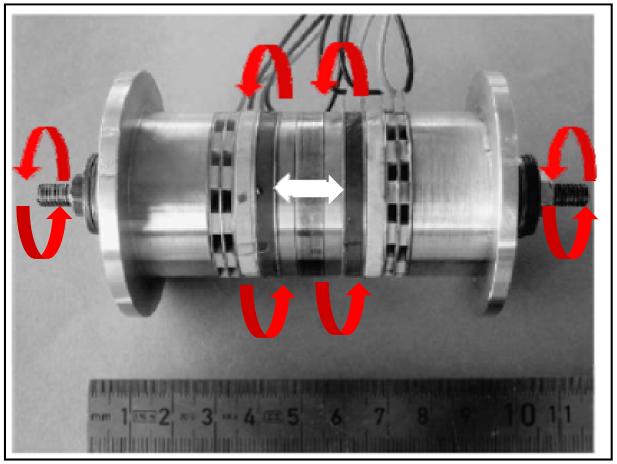
- **Torsional mode (T)**



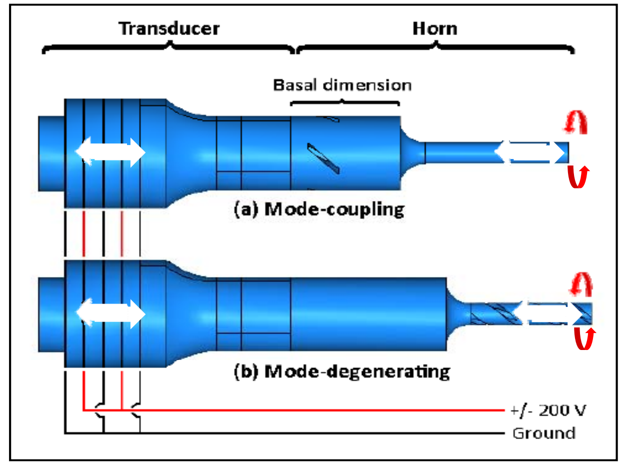
- **Coupling of modes.**
- **Degeneration of longitudinal mode.**

Ultrasonic applications:

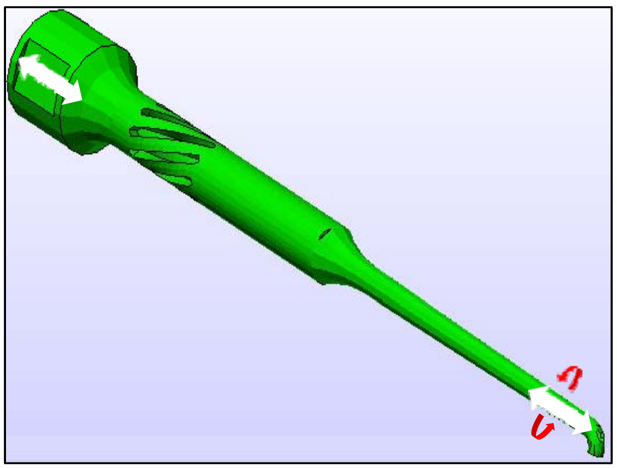
- Ultrasonic motor



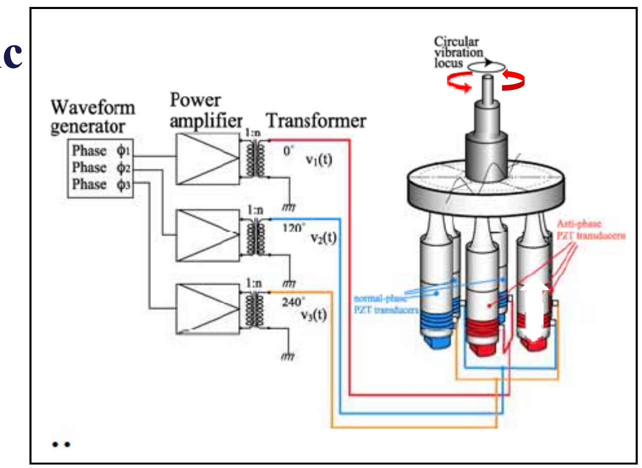
- Ultrasonic drilling



- Ultrasonic tissue dissection



- Ultrasonic welding



Coupling of modes:

- **L mode:**
- **T mode:**

$$C_L = nC_T$$

$$\lambda_L = \frac{C_L}{f} \qquad \longleftrightarrow \qquad \lambda_T = \frac{C_T}{f}$$

$$\lambda_L = n\lambda_T$$

- **Uniform cross-sectional parts:**

$$C_L = \sqrt{E/\rho} \qquad\qquad C_T = \sqrt{E/2\rho(1+\nu)}$$

- **Non-uniform cross-sectional parts :Exponential horn**

$$C_L' = \frac{C_L}{\sqrt{1-(\beta C_L/\omega)^2}} \qquad\qquad C_T' = \frac{C_T}{\sqrt{1-(2\beta C_T/\omega)^2}}$$

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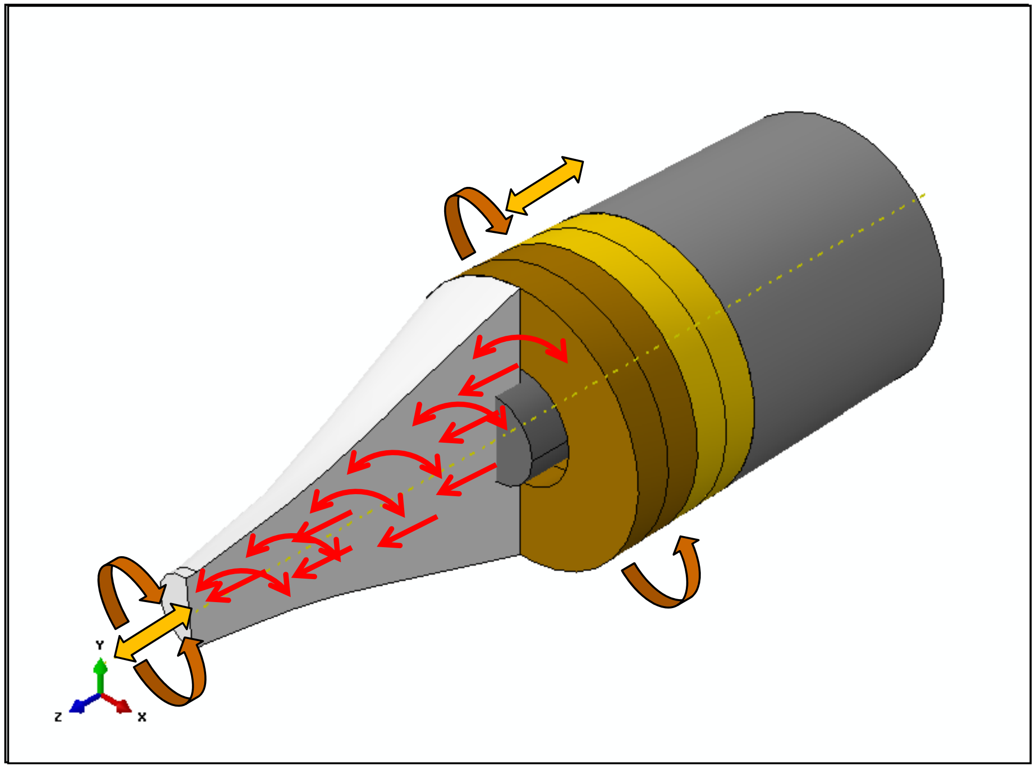
Coupling of modes in Langevin transducer:

- **Two sets of piezoceramics.**
- **Determine the f_r, materials.**
- **β calculated from L and T wave equations.**
- $\beta = \dfrac{lin\frac{R_1}{R_2}}{L}$



Coupling of modes:

- **Advantages:-**
  1- produces high response.

  2- produces high torsionality.

  3- L and T response can be controlled independently.

- **Disadvantages:-**
  1- requires two power generators.

  2- requires expensive tangentially poled piezoceramics.

  3- difficult to secure into an enclosure.

  4- difficult to keep the same resonance frequency under different load conditions.

  5- Working surface decided by the decay coefficient.

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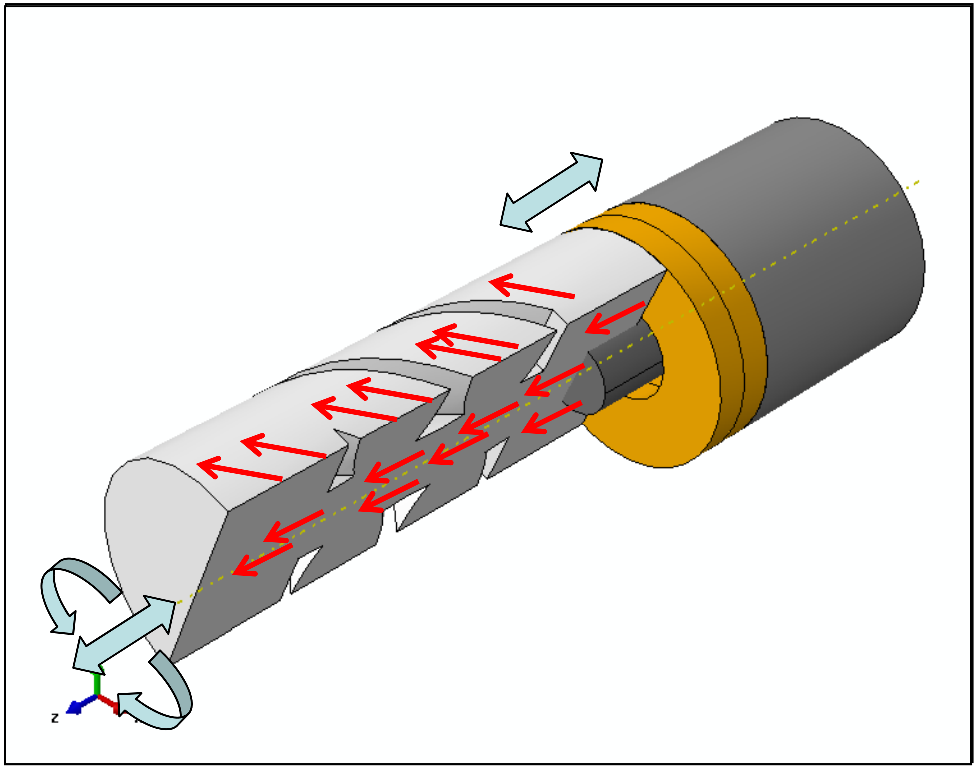
Degeneration of L mode:

- **Modify the wave path of L transducer.**
- **Slots dimensions, location, the helix angle.**



Degeneration method:

- **Advantages:-**

  1- requires only a longitudinal excitation.

  2- inexpensive fabrication.

  3-easy to secure into an enclosure.

  4- more resonance stability under different load conditions.

Disadvantages:-

1- low torsionality.

2- coupling with surrounding unwanted modes.

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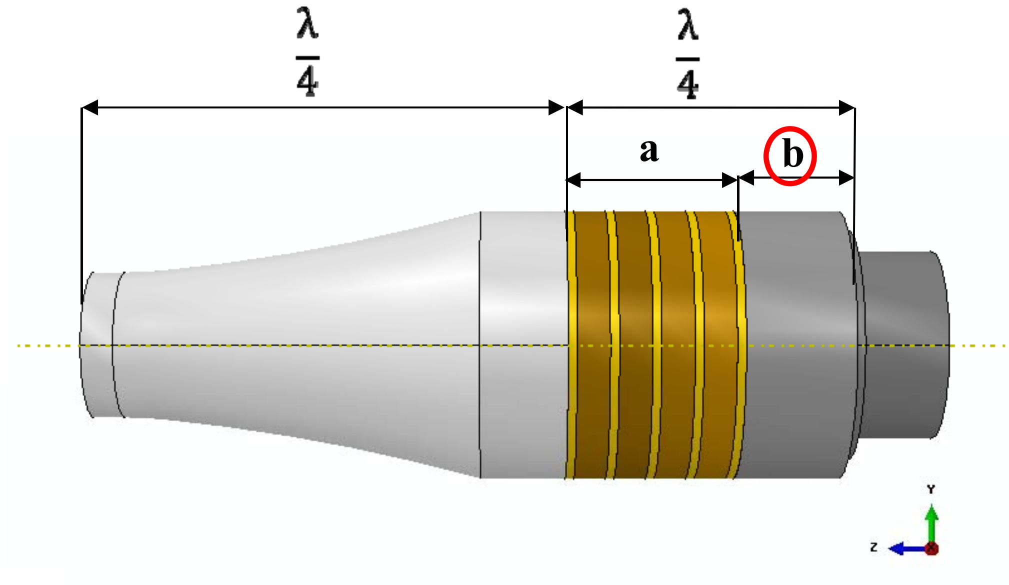
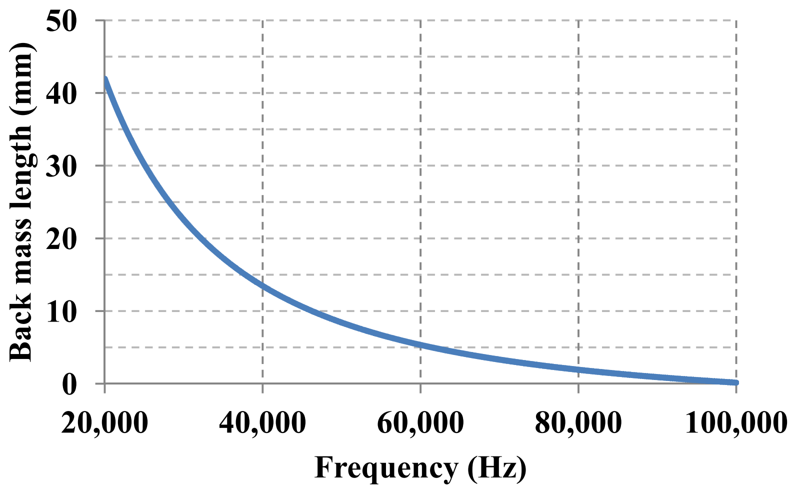
New approach:

- f_r , Z_a , Z_b , a.

$$\sum \frac{Z_a}{Z_b} \tan\left(\frac{\omega a}{v_a}\right) \tan\left(\frac{\omega b}{v_b}\right) = 1$$

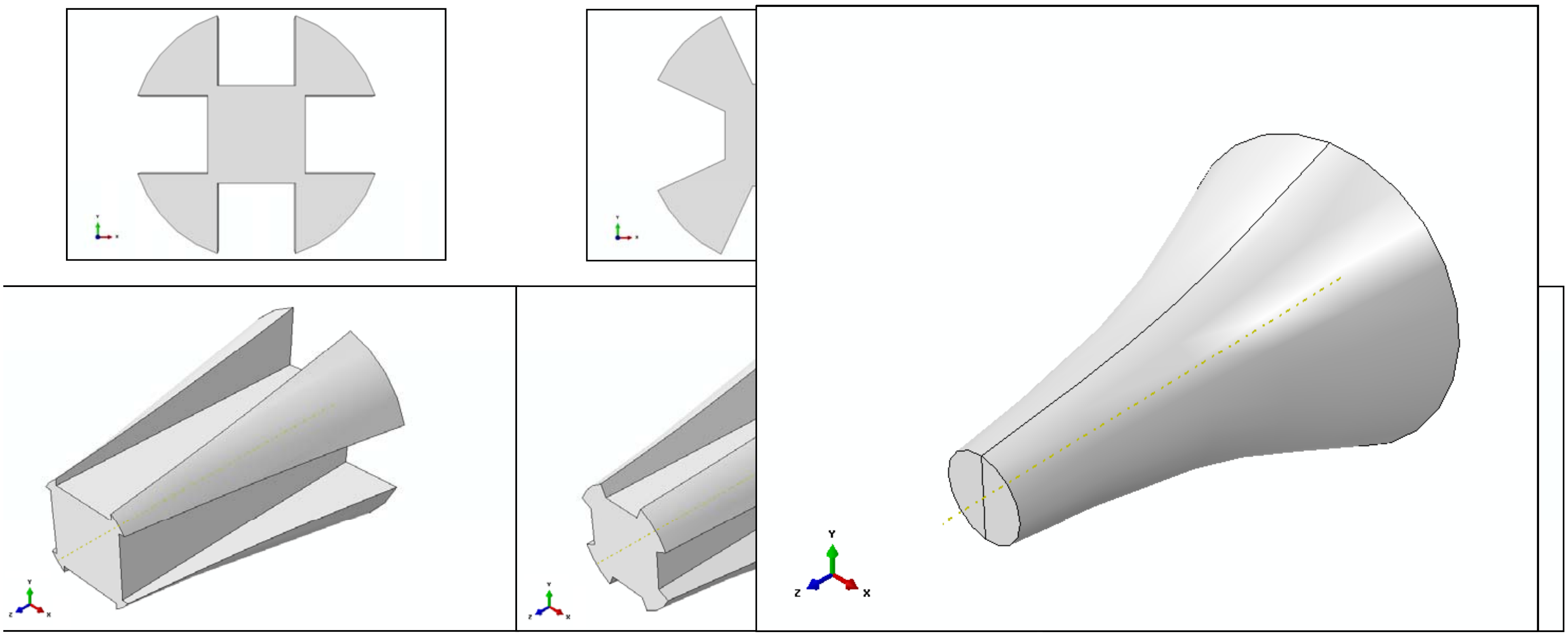
- **Output surface is decided by the application requirement.**





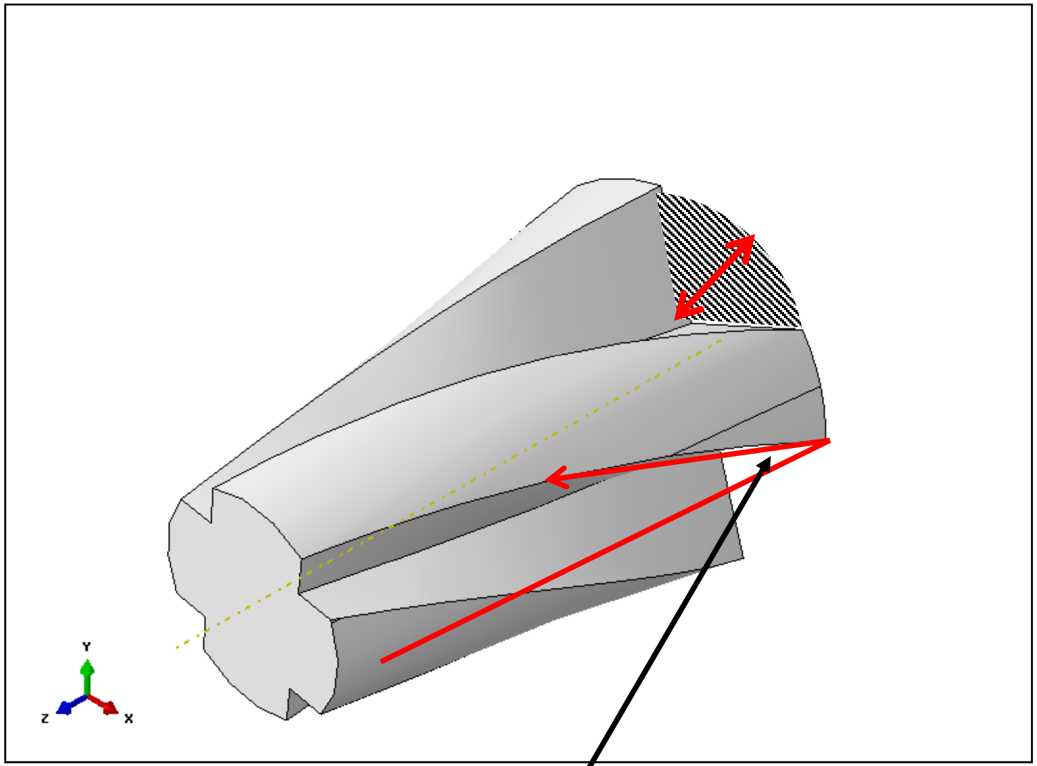
New approach

Case 1 Case 2 Case 3



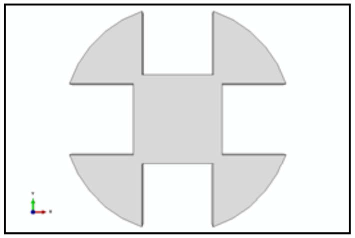
Design parameters:

- Depth of cut.
- Area of cut.
- Helix angle.
- Torsionality.
- Frequency spacing.
- Relative response.
- Nodal plane position.

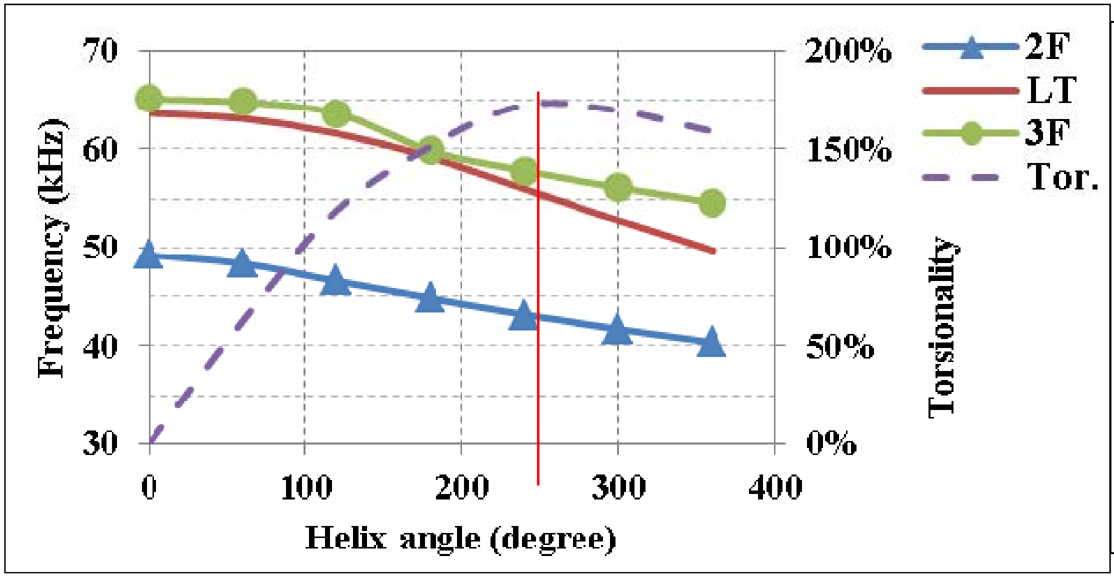


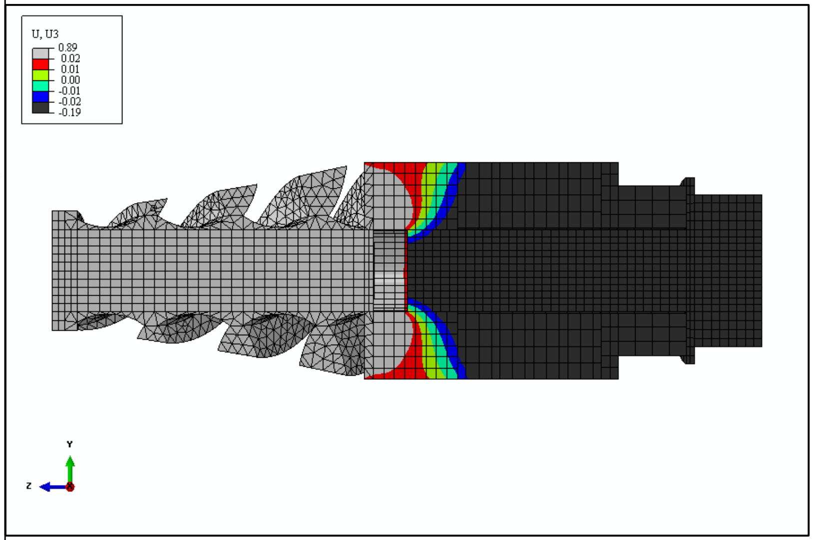
Helix angle

Case 1



Max. Torsionality	170%
Frequency spacing	3%
Max./Min. responses	4.3





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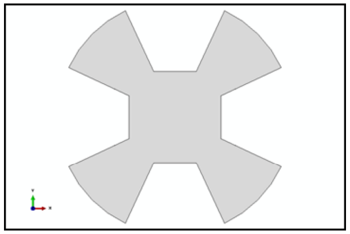
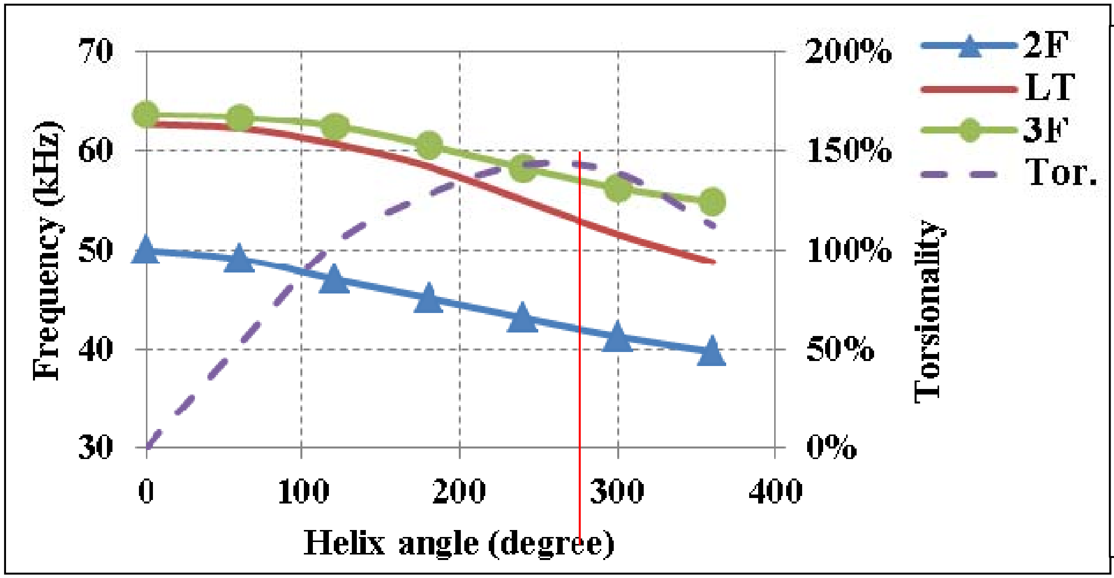
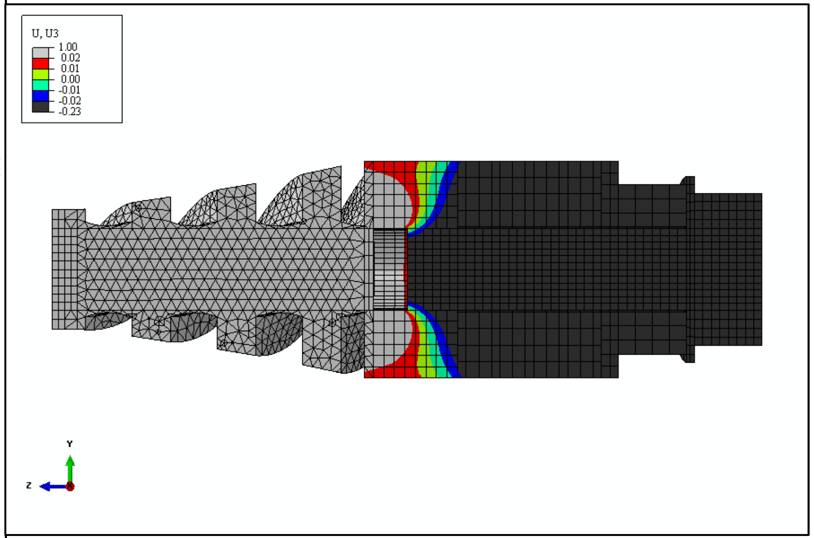
Case 2

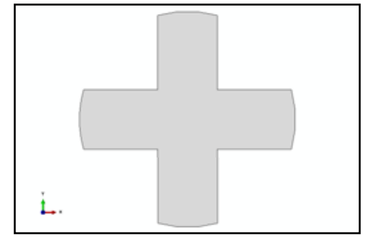


Max. Torsionality	140%
Frequency spacing	5%
Max./Min. responses	4.0

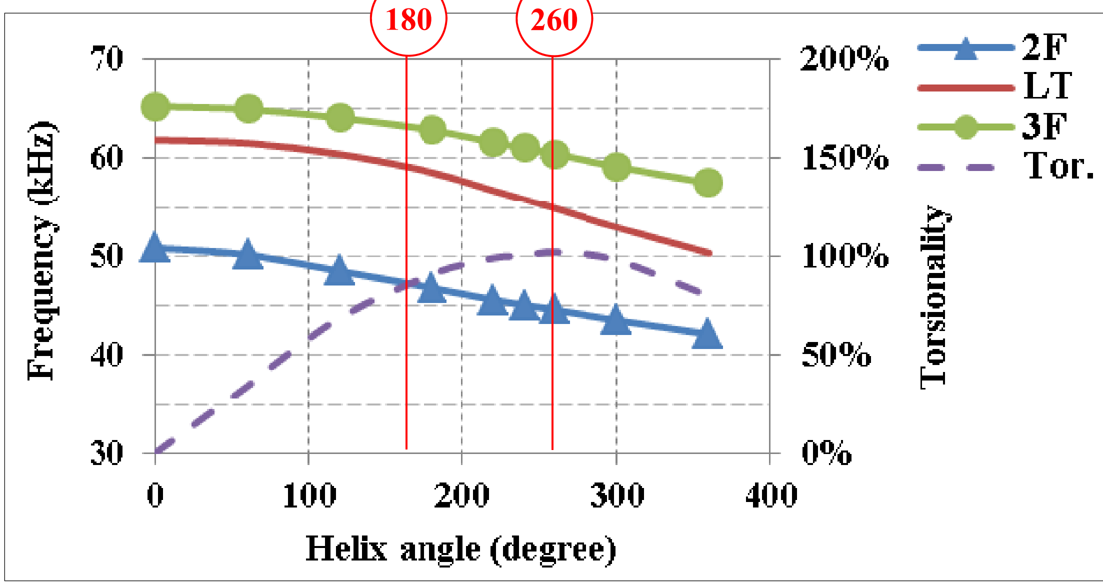


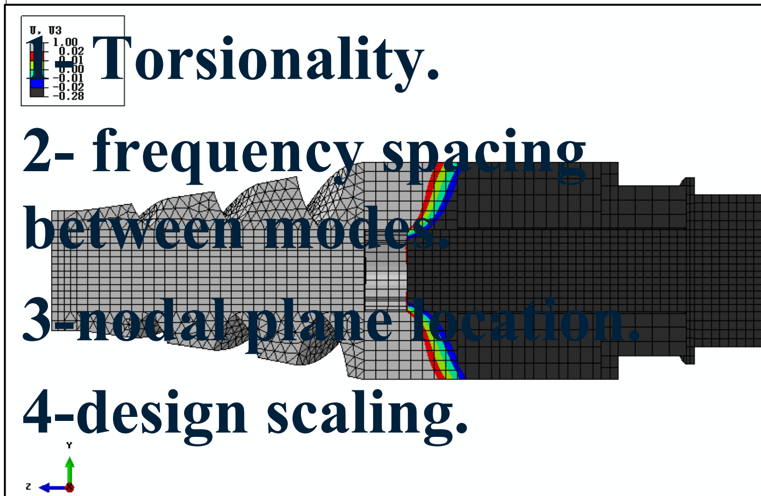


Case 3



Max. Torsionality	**102%**
Frequency spacing	**12%**
Max./Min. responses	**3.7**





1- Torsionality.

2- frequency spacing between modes.

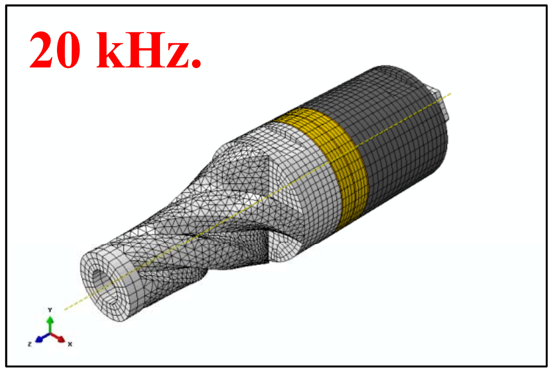
3-nodal plane location.

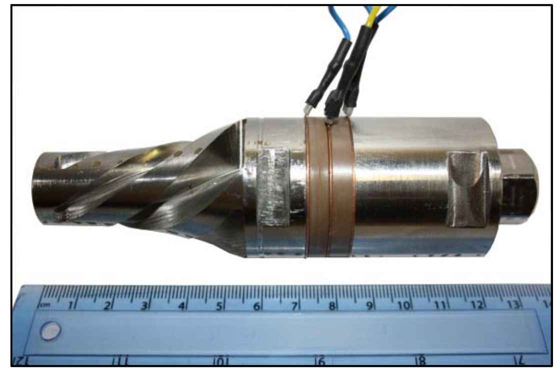
4-design scaling.

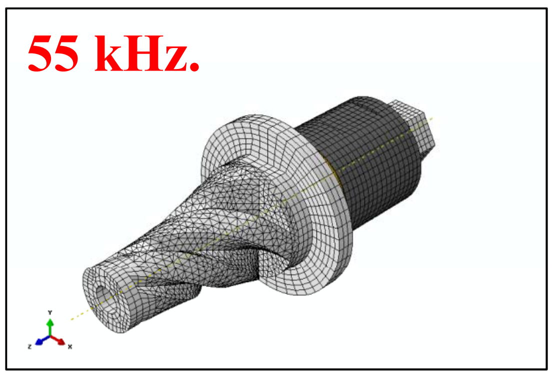
Analysis techniques:

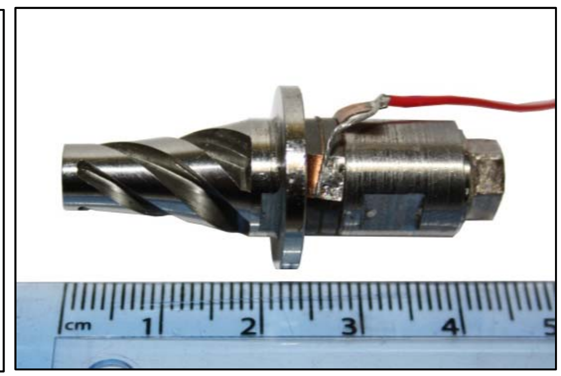
- Finite element analysis.
- Experimental analysis.

* Modal analysis.
* Harmonic analysis.
* Electrical analysis.









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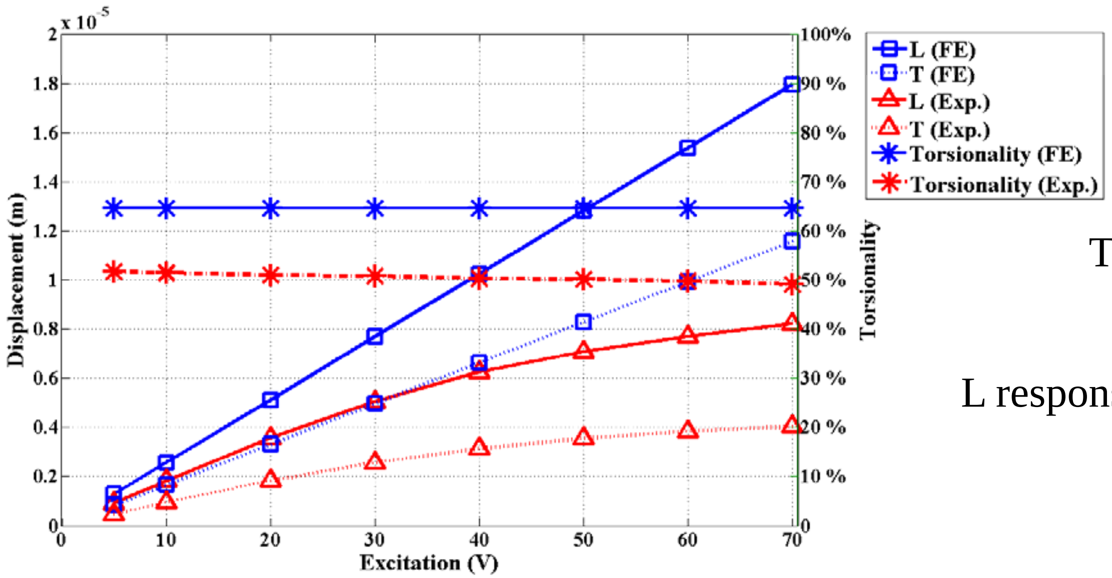
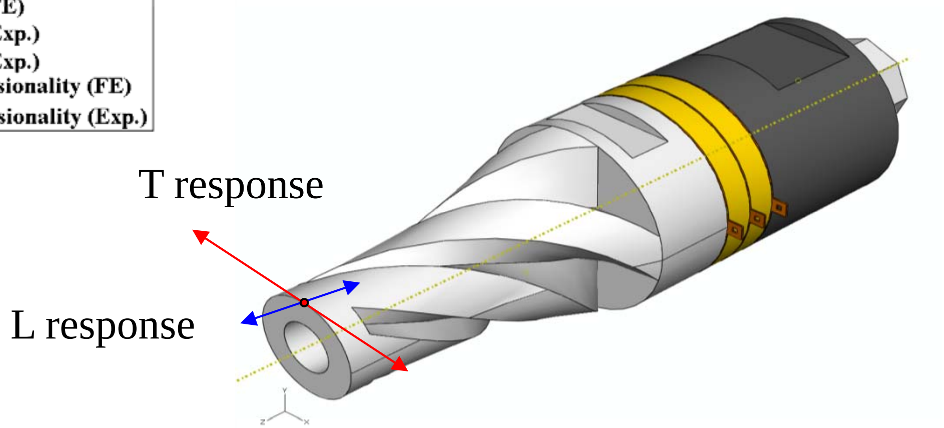
1- Torsionality:

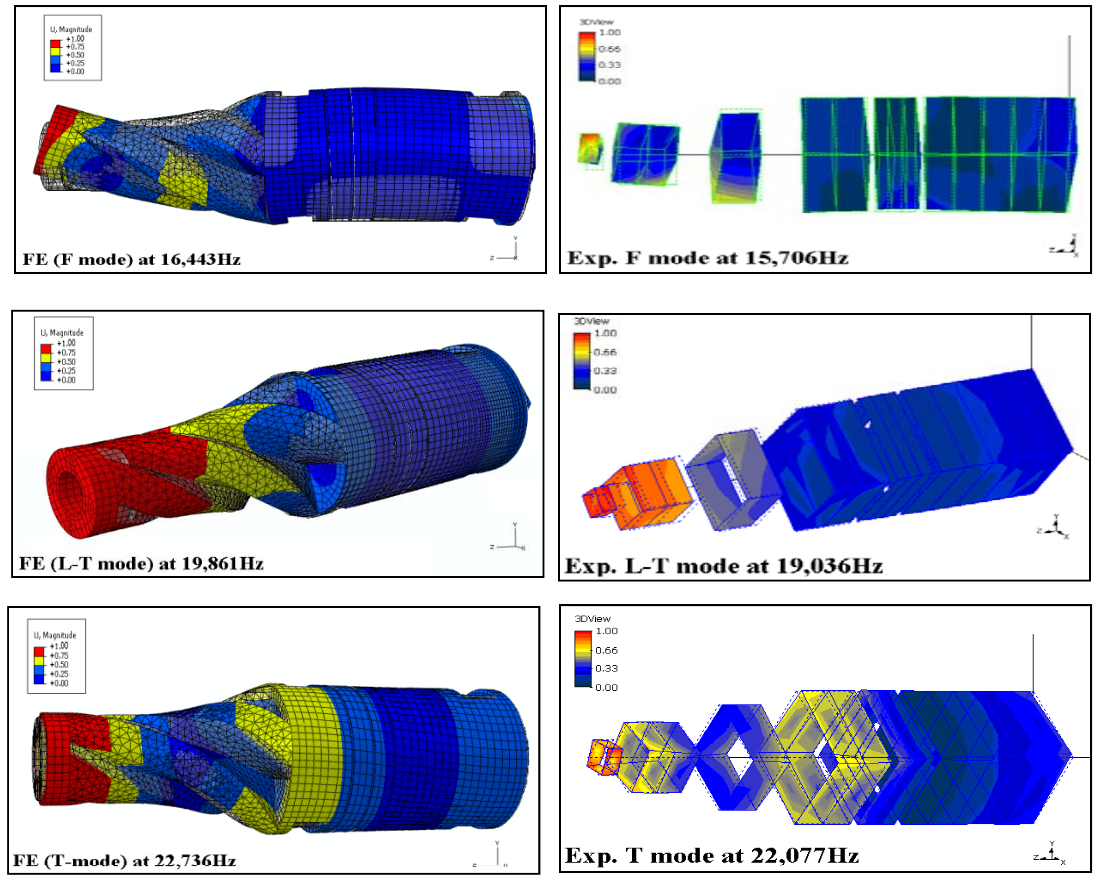


Numerical and experimental response peaks and torsionality for different excitation voltages



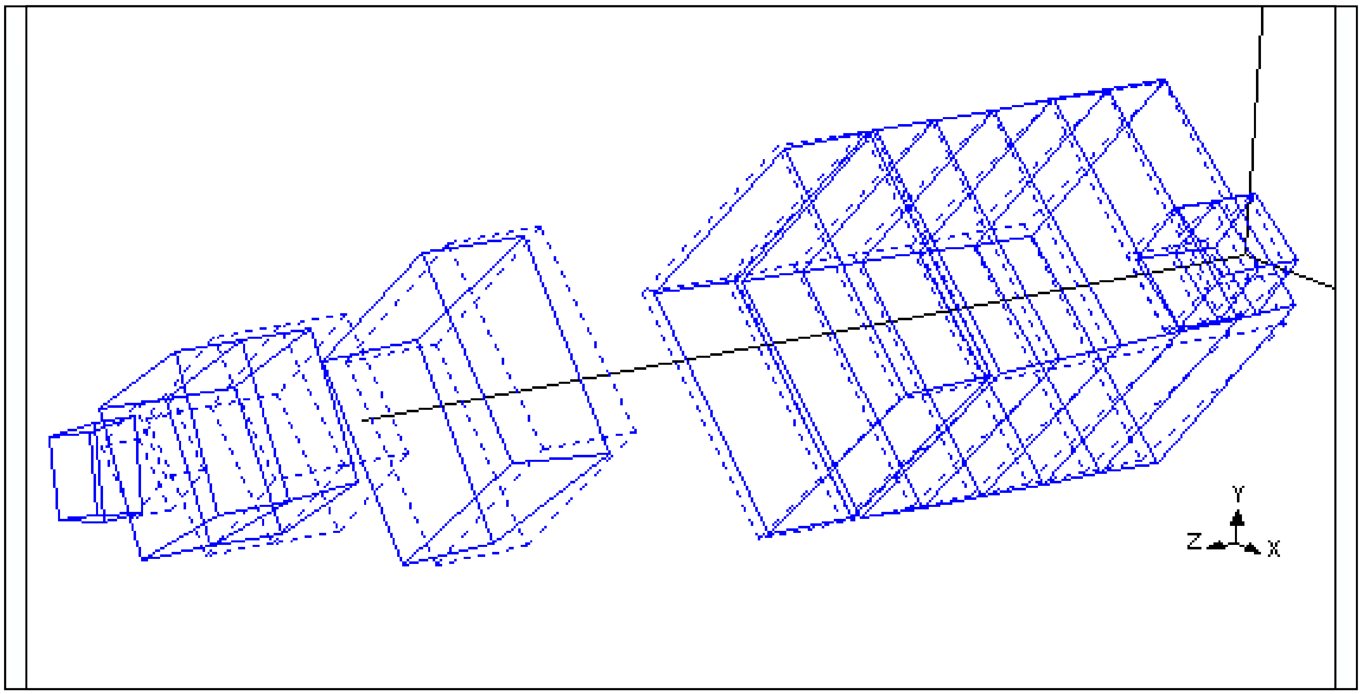
2- Frequency spacing:

	Modes	Model 1	Model 2
FE	LT-2F	20.8%	18%
	LT-3F	14.5%	20%
Exp.	LT-2F	21.2%	
	LT-3F	18.1%	



Numerical (left) and experimental (right) modal analysis of the desired and surrounding modes.

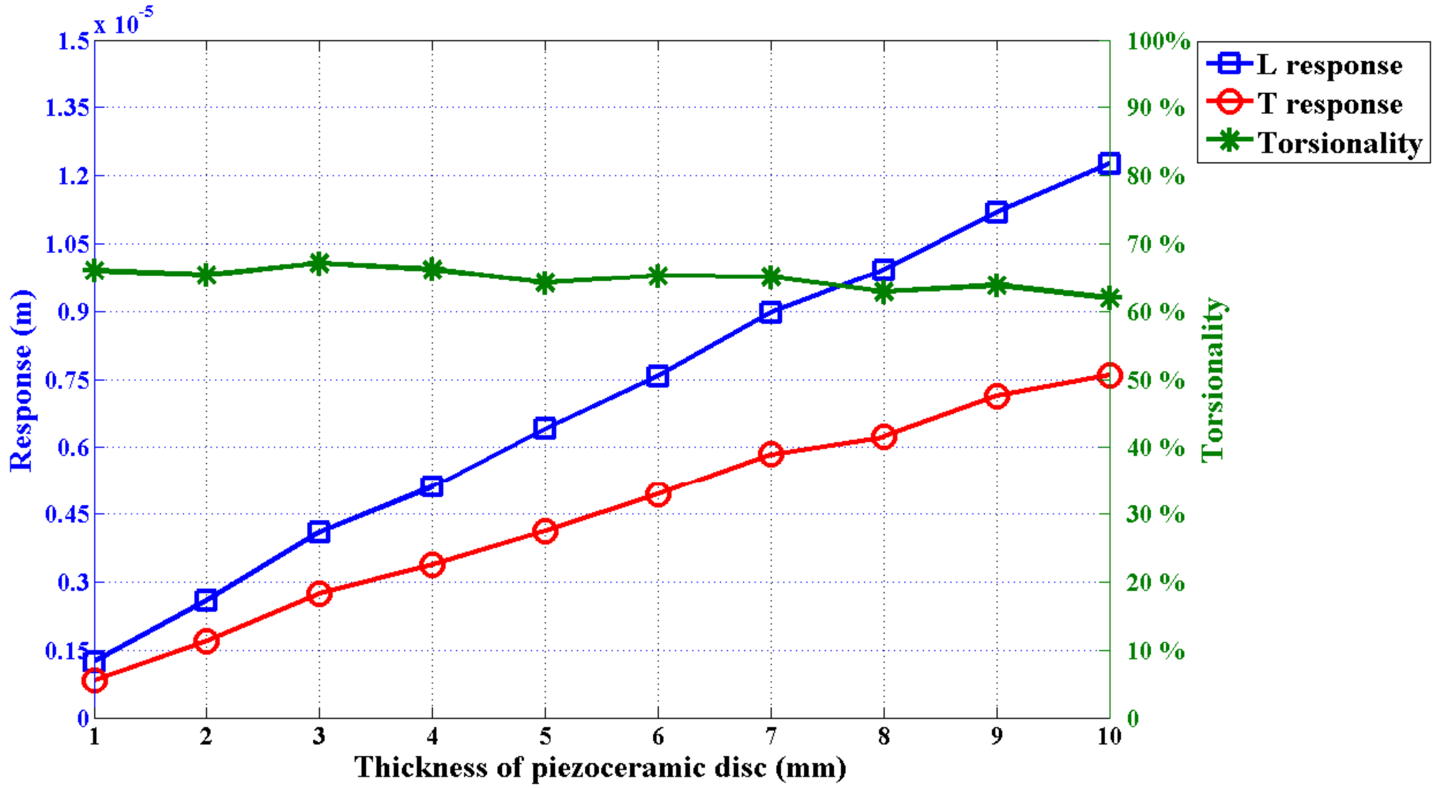
3- Location of nodal plane:



Numerical (FEA) wire frame results of longitudinal vibration response.

Experimental (EMA) wire frame results of longitudinal vibration response.

4- Design scaling:



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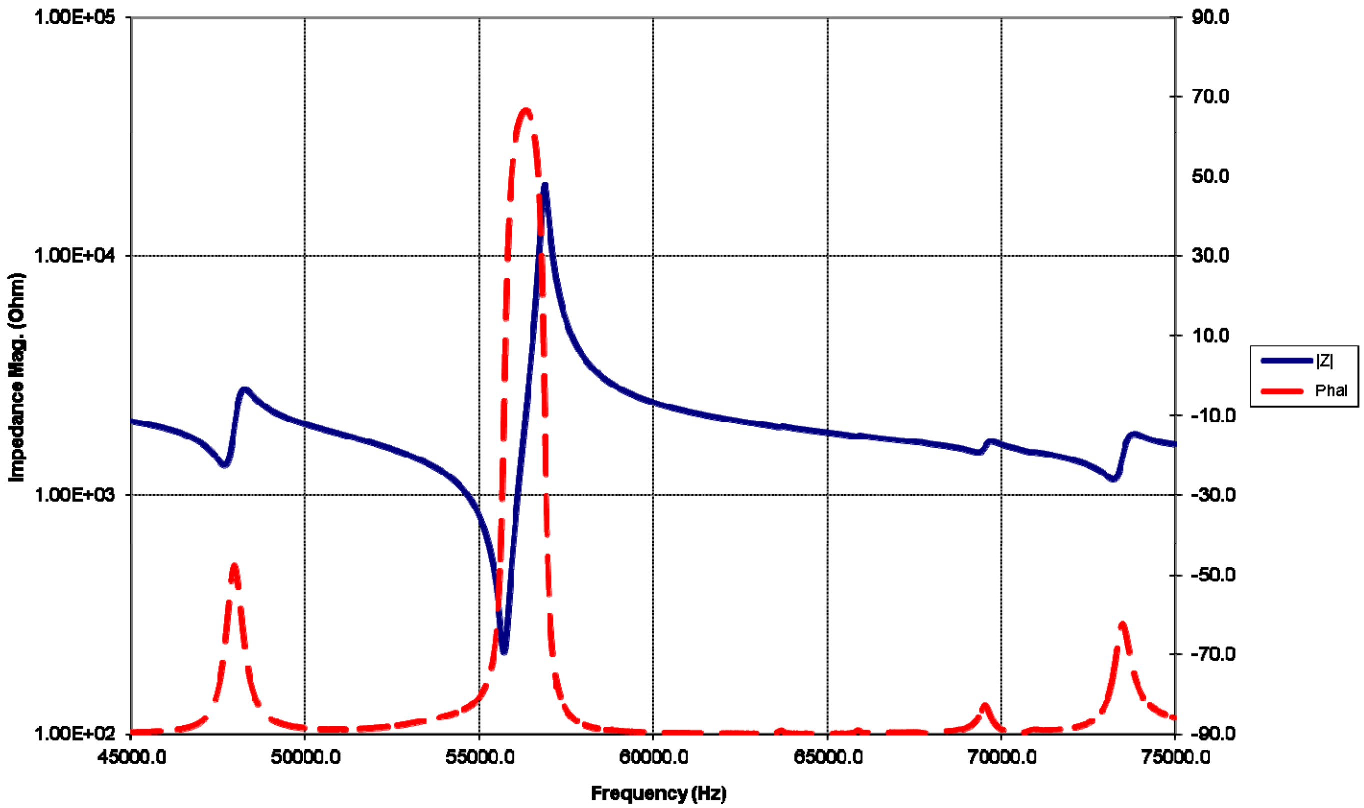
5- Electrical analysis:



Conclusions:

- **Employing the advantages of two methods can produce a design which overcomes their disadvantages.**
- **The proposed model is simple in design, excitation and securing features.**
- **It can be designed in different sizes which are suitable for a range of ultrasonic applications.**
- **It has good dynamic characteristics including good separation between modes and stability under different operation conditions.**

Thank you