Impeller stress & frequency prediction model

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1. Introduction

Impeller stress & frequency calculation method

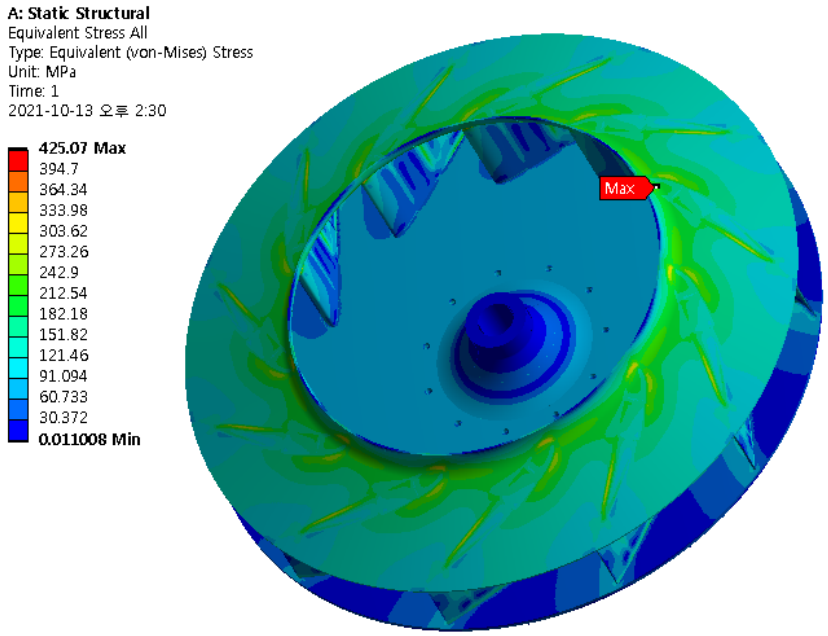
1. Using FAD

MATERIAL AND THICKNESS

	Material	Density g/cm³	Thick (mm)		Max kg/cm²	Allow kg/cm²
MAIN	HT60	7,85	9		1,690	2,830
SIDE	HT60	7,85	3,2		2,634	2,830
			Side Plate Bending ==>		7,925	3,144
MIDDLE	HT60	7,85	0		0	2,634
VANE	HT60	7,85	3,2	3,2	1,521	3,144
TV * TVb		RIB NO.	2			
EXTRA WEIGHT:		0	kg			

Recalculate

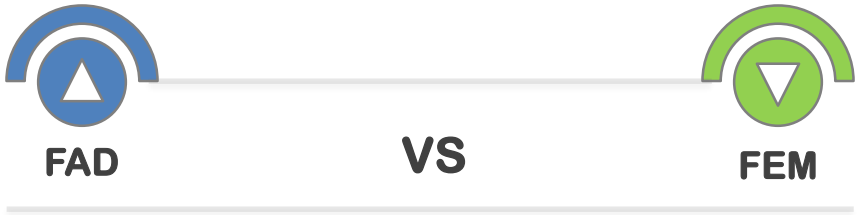
2. Using FEM (Ansys Mechanical)



** Note: FAD is Tongyang self-developed program while Ansys is purchased with 1 license.*

1. Introduction

Comparison of stress & frequency prediction method



	FAD	FEM	
Accuracy	50%	90%	Accuracy
Speed	100%	20%	Speed
Cost	90%	15%	Cost
Easy to use	80%	30%	Easy to use
Frequency calculation	No	Yes	Frequency calculation

** Note: value higher is better*

1. Introduction

COMMENTS:

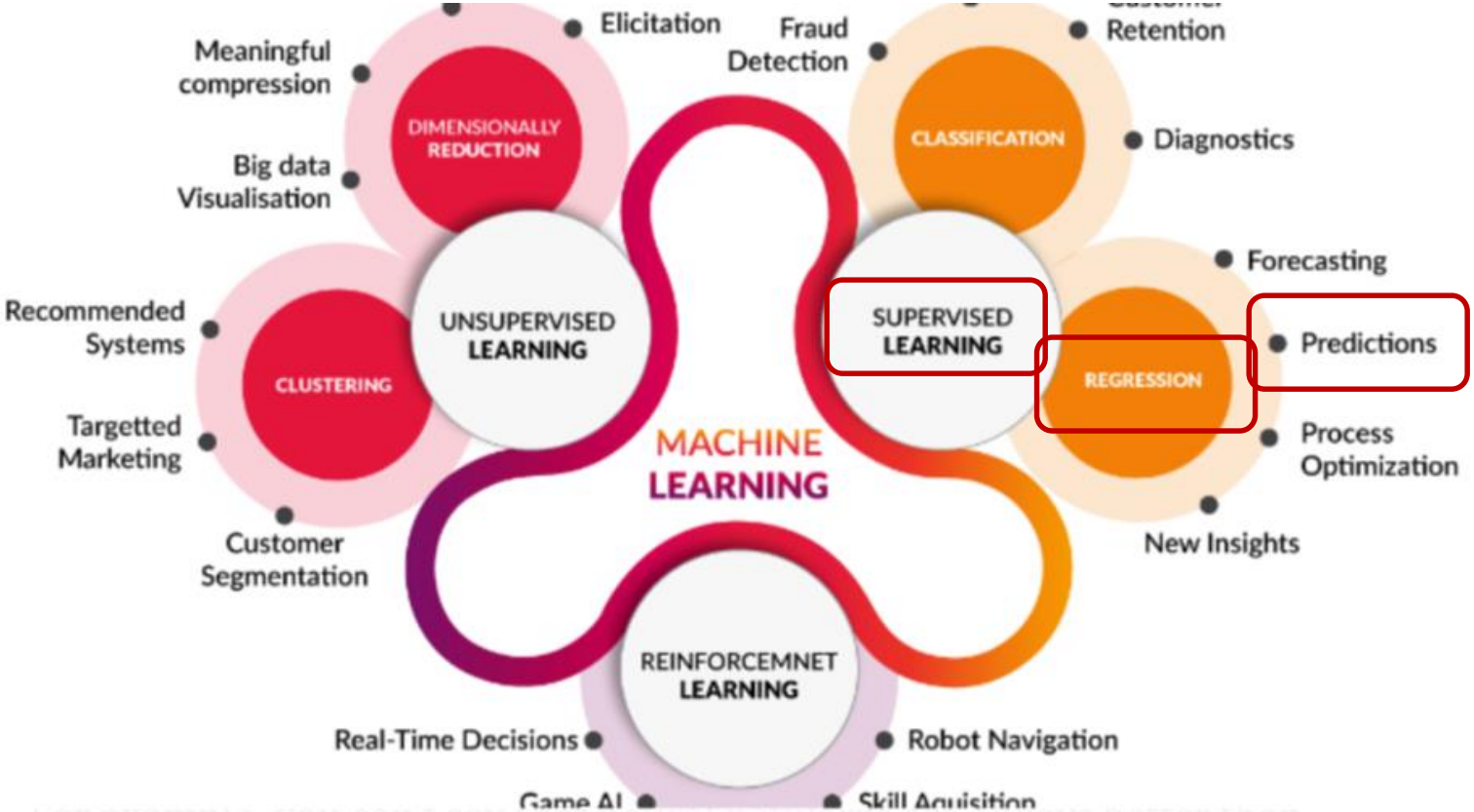
- Using FAD is fast to get the result but the margin is high ➔ can not reduce impeller's cost to improve competitiveness.
- Using FEM can get high accuracy result ➔ can help to design lightweight impeller to reduce cost & improve competitiveness.
- Problem with FEM is expensive license & long calculation time ➔ can not apply to many projects.

➔ It's needed to develop a new tool which is as fast as FAD but also has good accuracy in stress & frequency prediction like FEM.

** Note: value higher is better*

2. Machine learning application

Machine learning algorithm tree map



Selected for stress prediction!

** Regression analysis in supervised learning algorithm can be use to predict impeller's stress!*

2. Machine learning application

Machine learning tools

** Python is a data science language & has a lot of library support for machine learning.*

** Jupyter notebook is a development tool to deploy machine learning using Python.*

3. Data preparation

Analysis data preparation process

Step 1
Define input parameters

Material properties:
- *Young modulus*
- *Density*

Design conditions:
- *Rotating speed*
- *Temperature*

Impeller's design:
- *Main diameter D2*
- *Main plate thick tm*
- *Side plate thick ts*
- *Vane thick tv*

Other parameters:
- *Vane rib*
- *Vane Rim, side rim …*

Step 2
Define output parameters

Stress:
- *Main plate stress Sm*
- *Side plate stress Ss*
- *Vane stress Sv*

Frequency:
- *1^{st} natural frequency*

Other properties:
- *Impeller's weight*
- *Impeller's GD2*

Step 3
Create data table

Material properties:
- *Young: 139 ~ 205 Mpa*
- *Density: 7.8 ~ 8.0 g/cm^3*

Design conditions:
- *Speed: 900 ~ 3600 Rpm*
- *Temperature: only affect to Young => not need.*

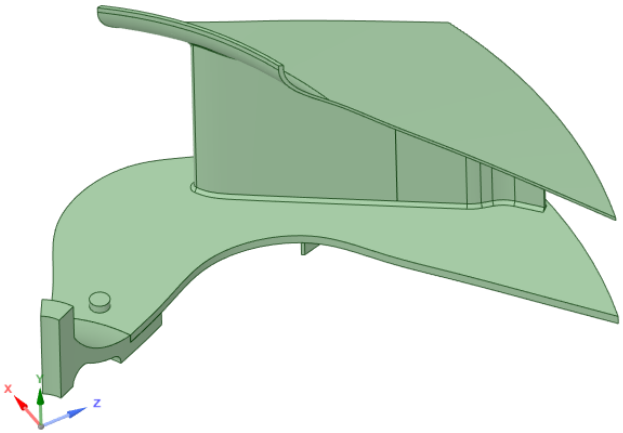
Impeller's design:
- *D2: 1000 ~ 2000 mm*
- *Tm: 3.2 ~ 18 mm*
- *Ts: 3.2 ~ 15 mm*
- *Tv: 3.2 ~ 9 mm*

** A total of 61 data rows were created from above conditions for model training.*
** A total of 13 data rows were created from above conditions for model testing.*

3. Data preparation

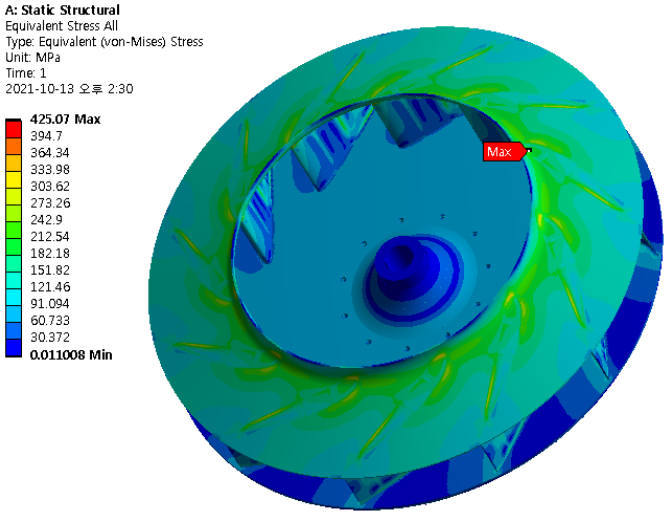
3D modeling & FEM analysis to get result

1. 3D modeling



H model was selected for modeling
3D model created for all parameters

2. FEM using Ansys Mechanical



FEM result for all cases (74 cases):

- *Main stress*
- *Side Stress*
- *Vane stress*
- *Natural frequency*

4. Data exploratory analysis

Data correlation value

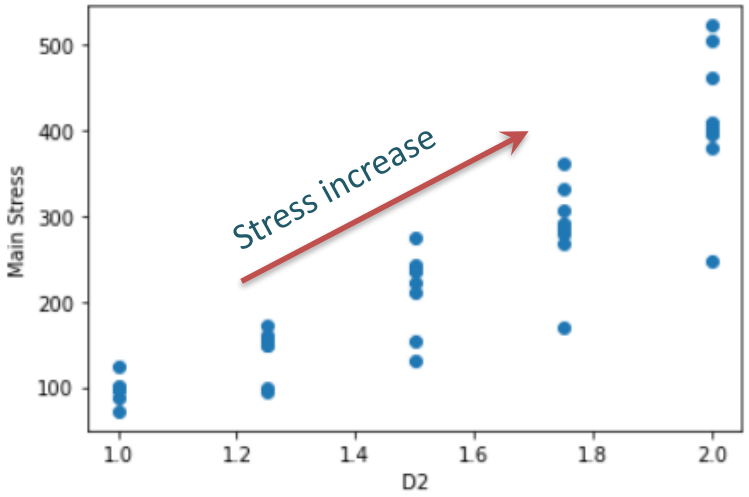
	D2	Tm	Ts	Tv
Weight	0.9556	0.7358	0.7562	0.3989
GD2	0.9364	0.6607	0.7438	0.3522
Sm	**0.9112**	0.3770	0.6396	0.4116
Ss	**0.6656**	0.4350	0.0434	0.5851
Sv	**0.9453**	0.6372	0.5540	0.2024
Frequency	0.0590	**0.6027**	0.0358	-0.0837

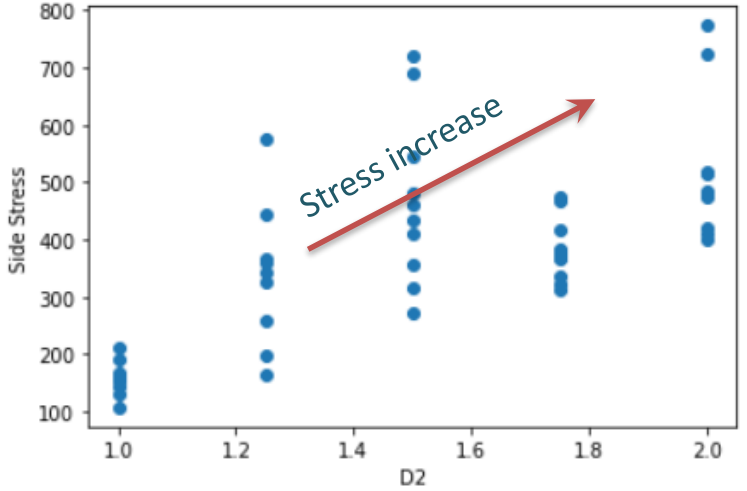
** High correlation value means 2 parameters might have strong relation.*

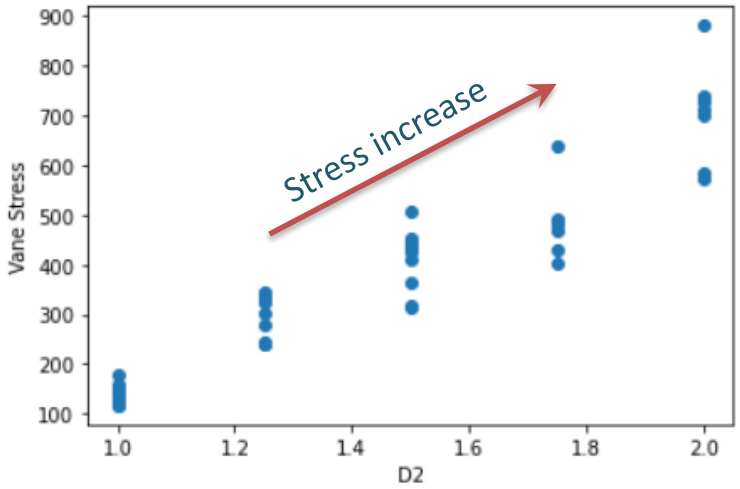
- *Sm, Ss, Sv & D2 has high correlation*
- *Frequency has high correlation with Tm (main thickness)*

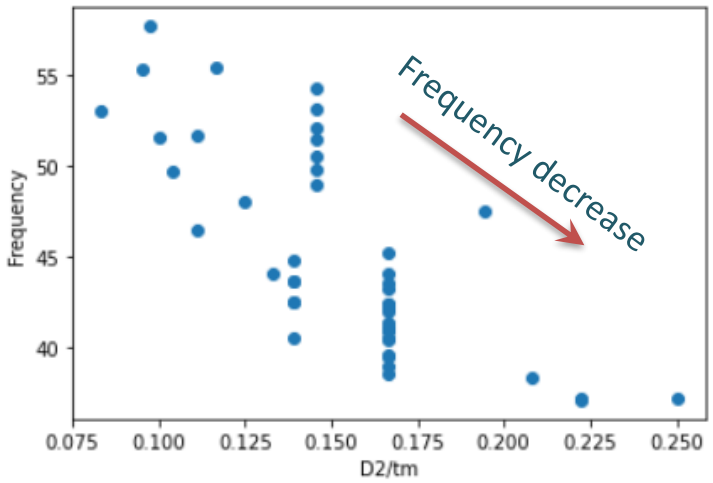
4. Data exploratory analysis

Scatter plots for data visualization





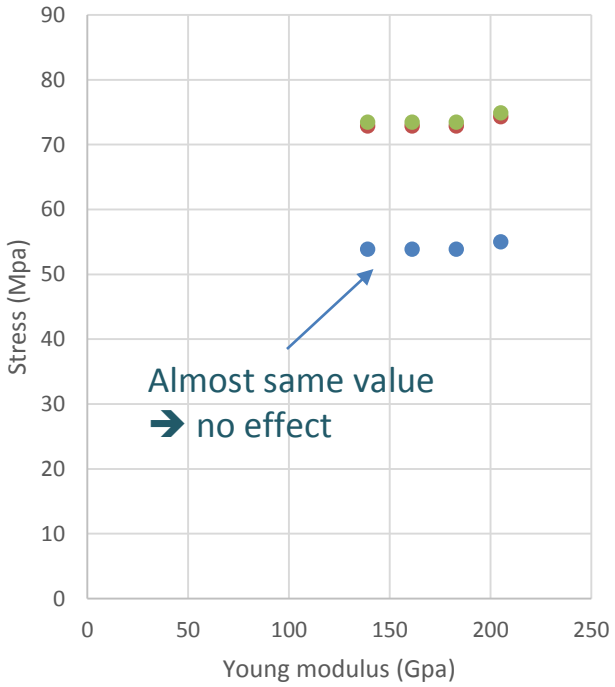




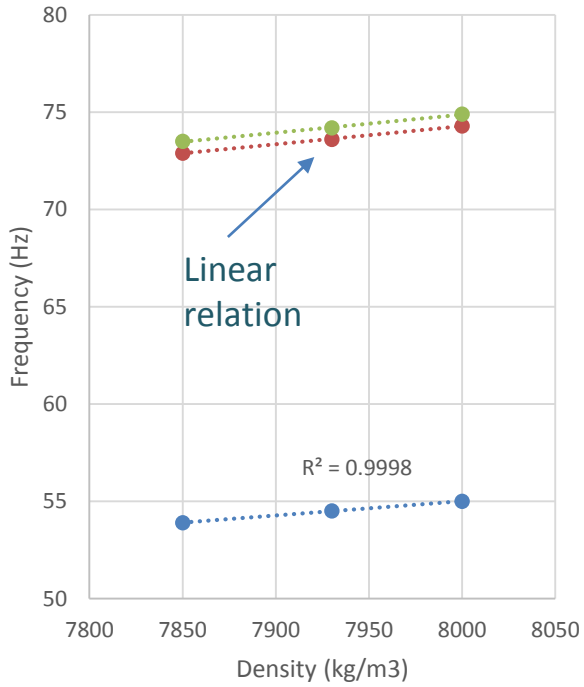
4. Data exploratory analysis

Stress vs Material properties & speed

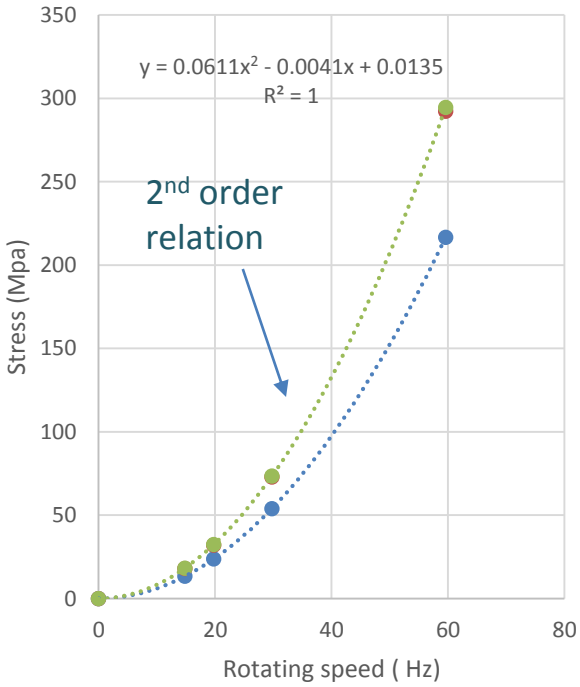
Stress vs Young modulus



Density



Stress vs rotating speed

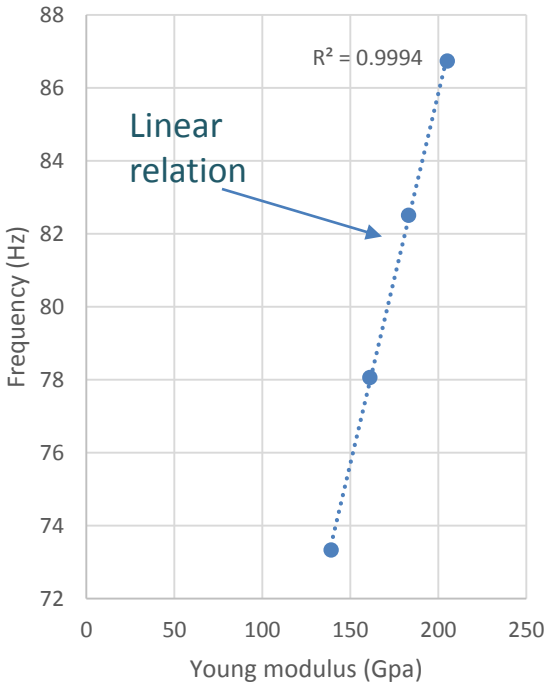


** Stress also can be calculated from a standard condition using above linear & 2nd order relationship!*

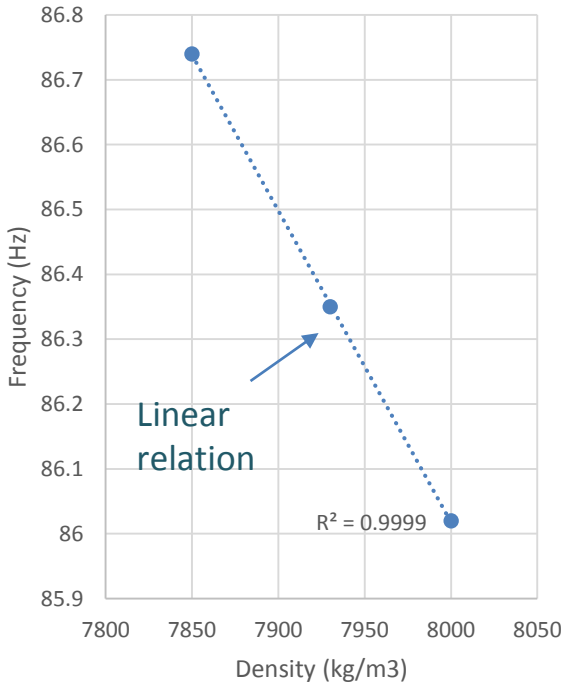
4. Data exploratory analysis

Frequency vs Material properties & speed

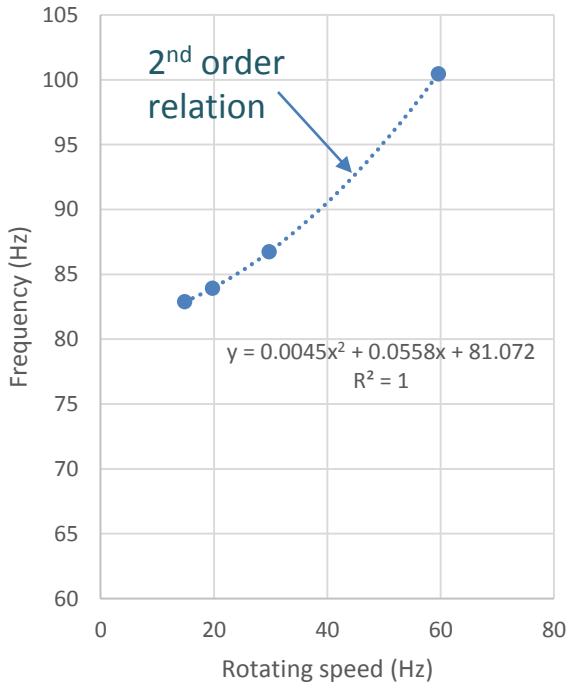
Frequency vs Young Modulus



Frequency vs Density



Frequency vs rotating speed



** Frequency has linear relationship with Young modulus & density ➔ it is possible to calculate frequency at different material condition from a standard condition!*

5. Regression modeling

2nd order polynomials regression model

** A 2nd order regression model for 4 input parameters included:*

- D2, tm, ts, tv

** Output included:*

- Sm, Ss, Sv, frequency, weight, GD2

The model has a form as below:

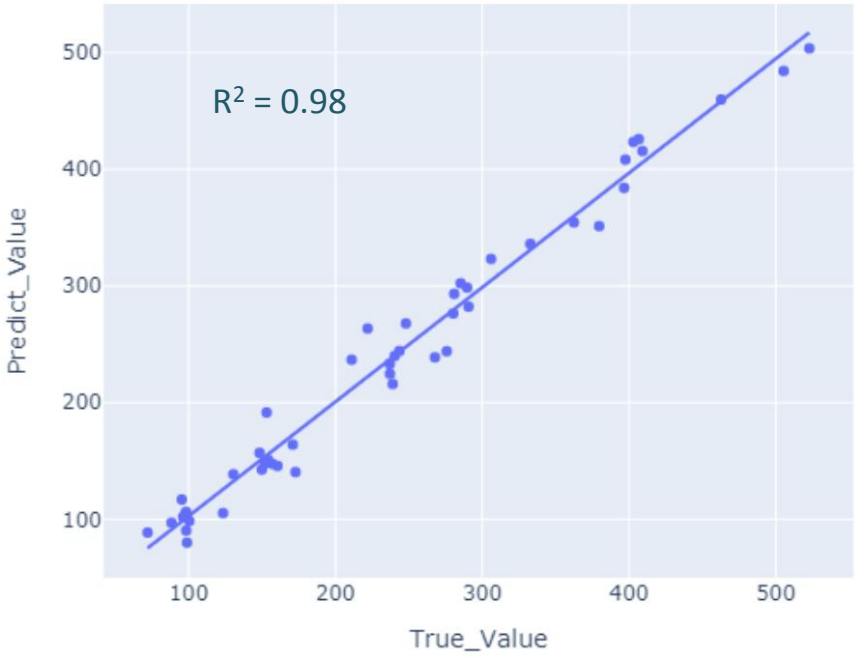
$$Y = a_0 + a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + b_1x_1^2 + b_2x_2^2 + b_3x_3^2 + b_4x_4^2 + c_1x_1x_2 + c_2x_1x_3 + \dots$$

** Sklearn Python library with linear regression solver was used to find the a0, a1, a2 … coefficients in above equation.*

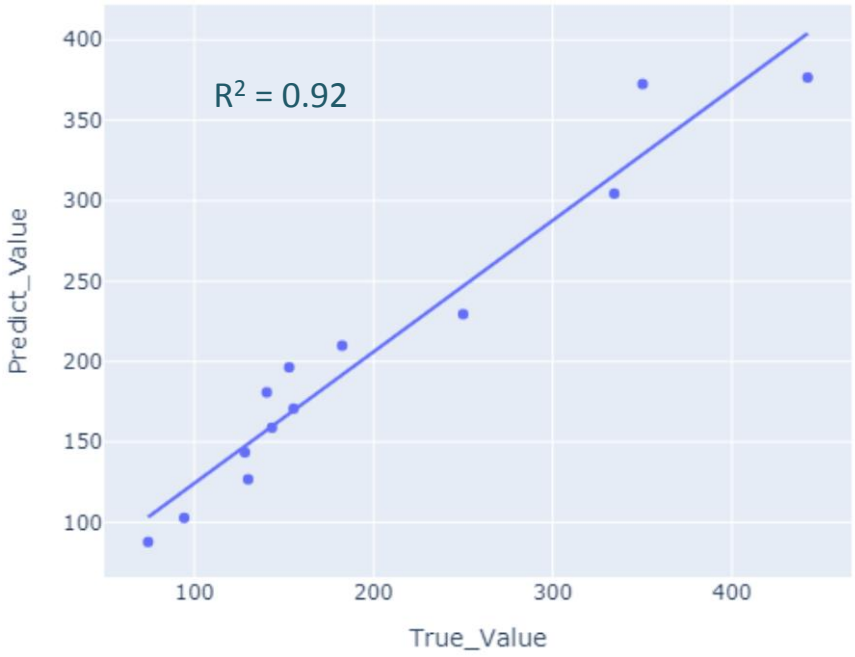
6. Modeling result

Model prediction – main stress

Train data prediction



Test data prediction



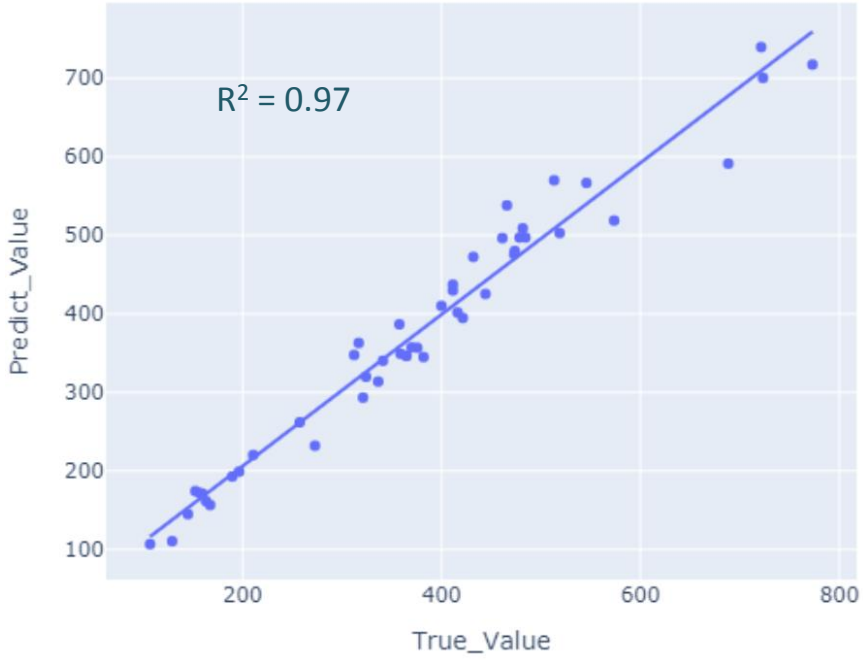
** Regression model has very high R^2 value ➔ high prediction accuracy!*

** All predicted values stay within +/- 10% of true values.*

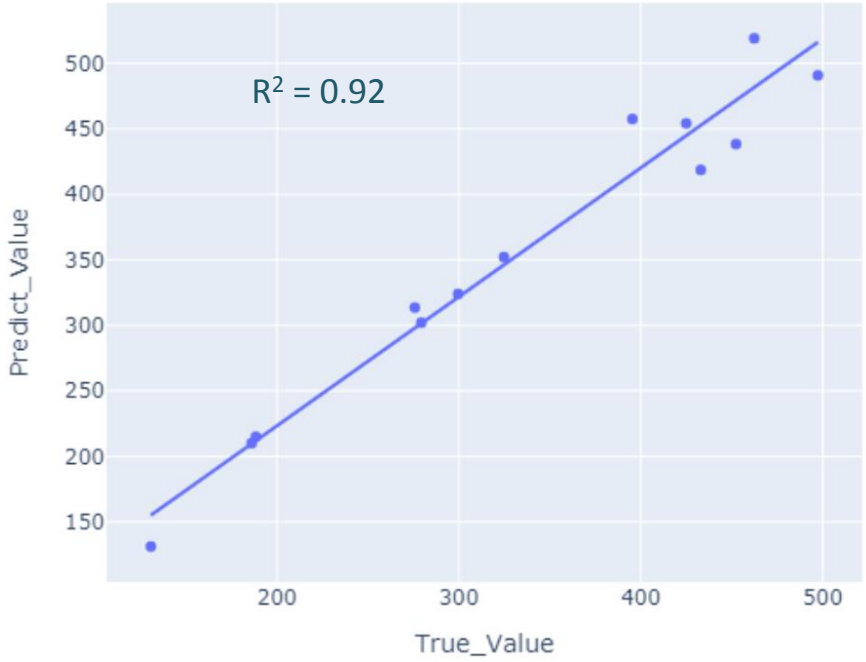
6. Modeling result

Model prediction – side stress

Train data prediction



Test data prediction



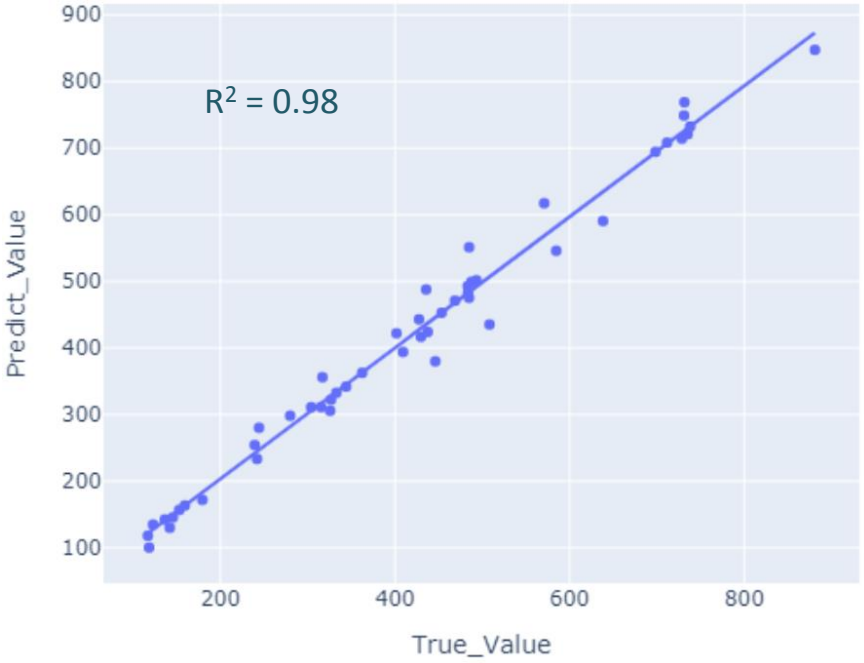
** Regression model has very high R^2 value ➔ high prediction accuracy!*

** All predicted values stay within +/- 10% of true values.*

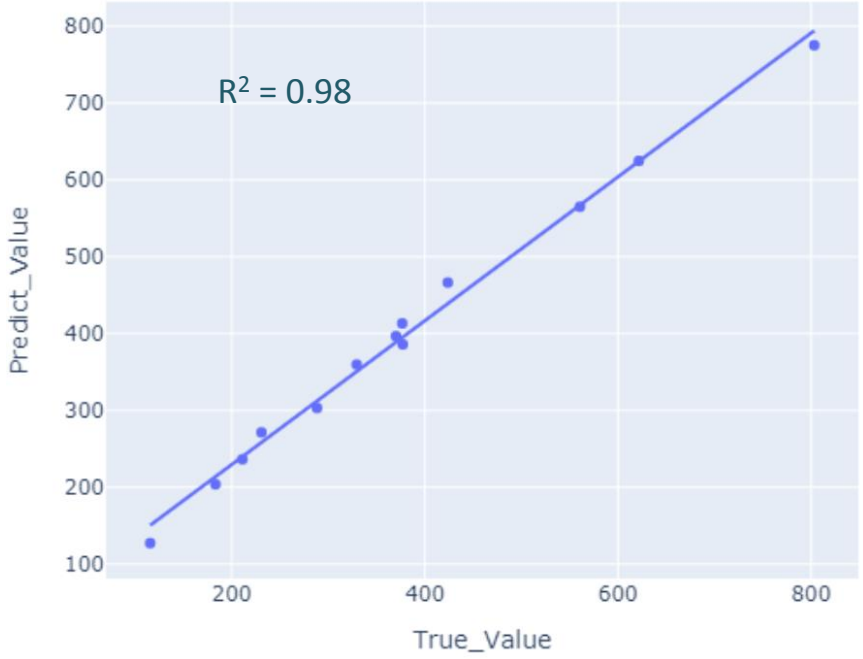
6. Modeling result

Model prediction – vane stress

Train data prediction



Test data prediction



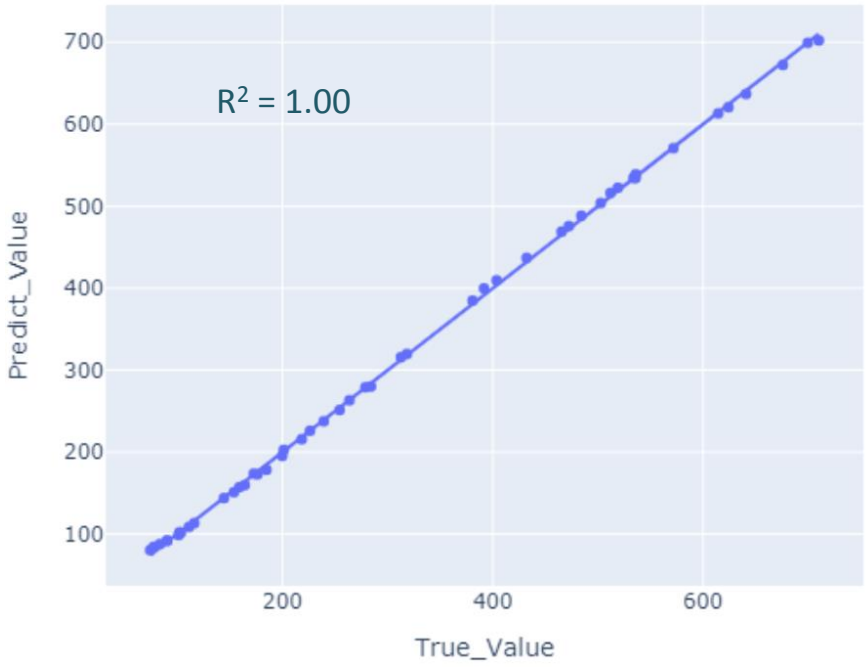
** Regression model has very high R^2 value ➔ high prediction accuracy!*

** All predicted values stay within +/- 10% of true values.*

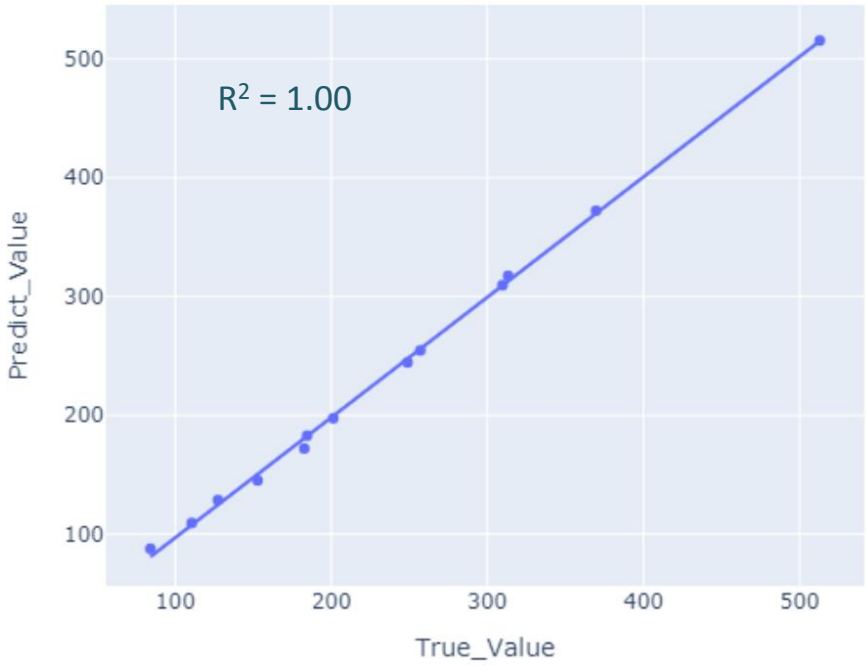
6. Modeling result

Model prediction – weight

Train data prediction



Test data prediction



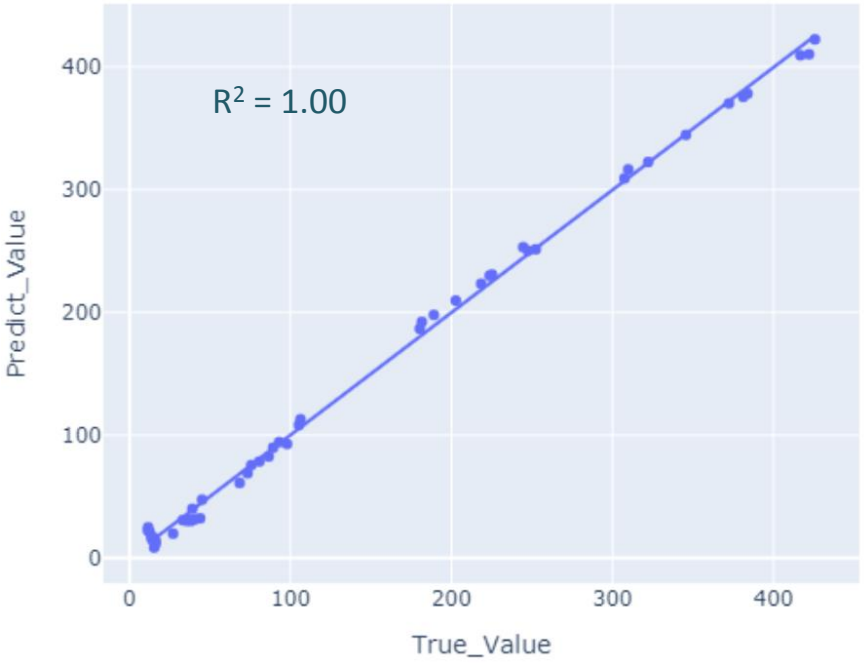
** Regression model has very high R^2 value ➔ high prediction accuracy!*

** All predicted values stay within +/- 3% of true values.*

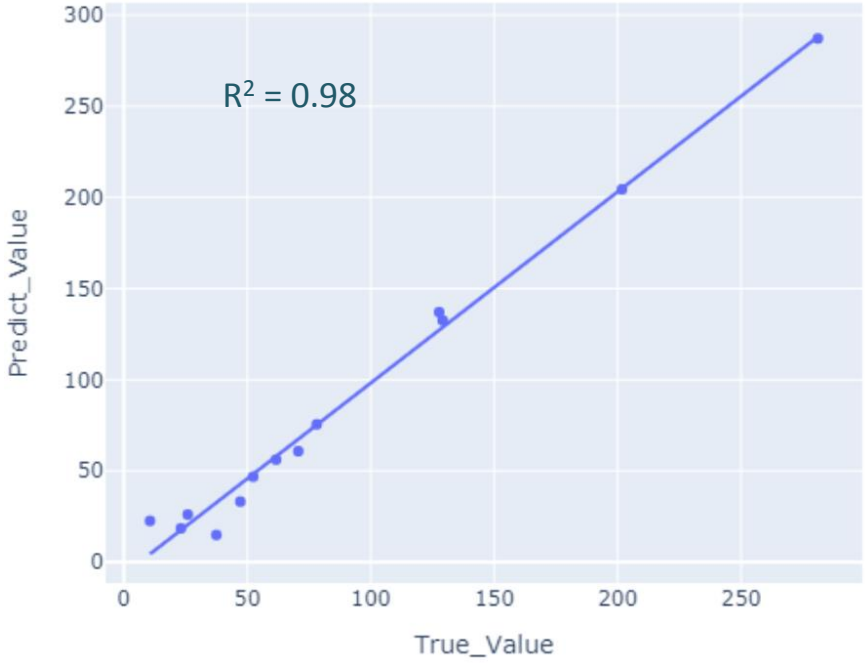
6. Modeling result

Model prediction – GD2

Train data prediction



Test data prediction



** Regression model has very high R^2 value ➔ high prediction accuracy!*

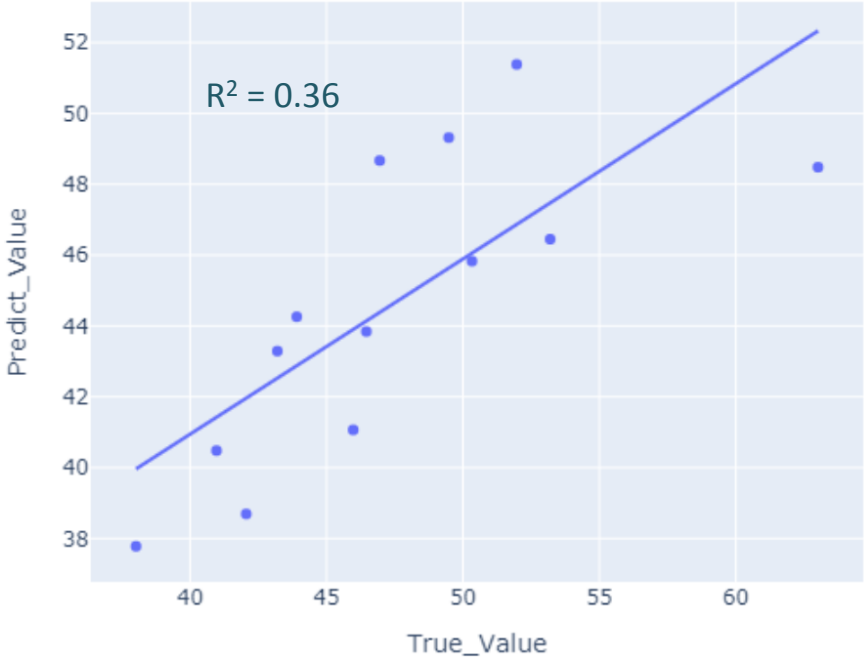
** All predicted values stay within +/- 5% of true values.*

6. Modeling result

Model prediction – frequency

Train data prediction

Test data prediction



** R^2 value of test data is quite low ➔ low prediction accuracy for frequency!*

** A new model should be developed to predict frequency instead of 2nd order model.*

6. Modeling result

Modified 2nd order polynomials regression model

** A 2nd order regression model for 3 input parameters included:*
- tm/D2, ts/D2, tv/D2
** Output included:*
- Frequency

The model has a form as below:

$$Y = a_0 + a_1 x_1^{p1} + a_2 x_2^{p2} + a_3 x_3^{p3} + b_1 (x_1^{p1})^2 + b_2 (x_2^{p2})^2 + b_3 (x_3^{p3})^2 + \ldots$$

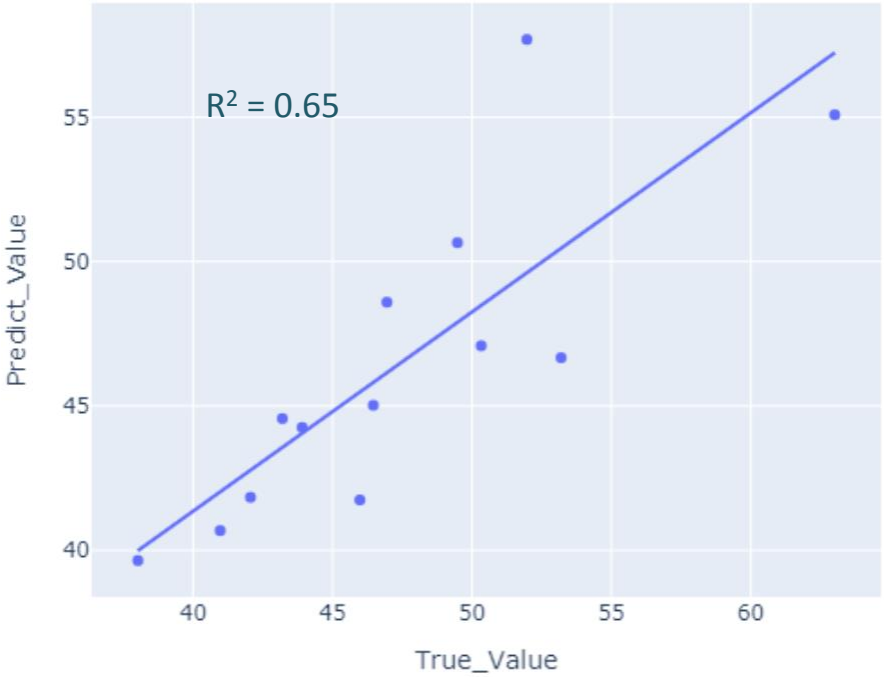
** Sklearn Python library with linear regression solver was used to find the a0, a1, a2 … coefficients and also p1, p2, p3 power value in above equation.*

6. Modeling result

New model prediction – frequency

Train data prediction

Test data prediction

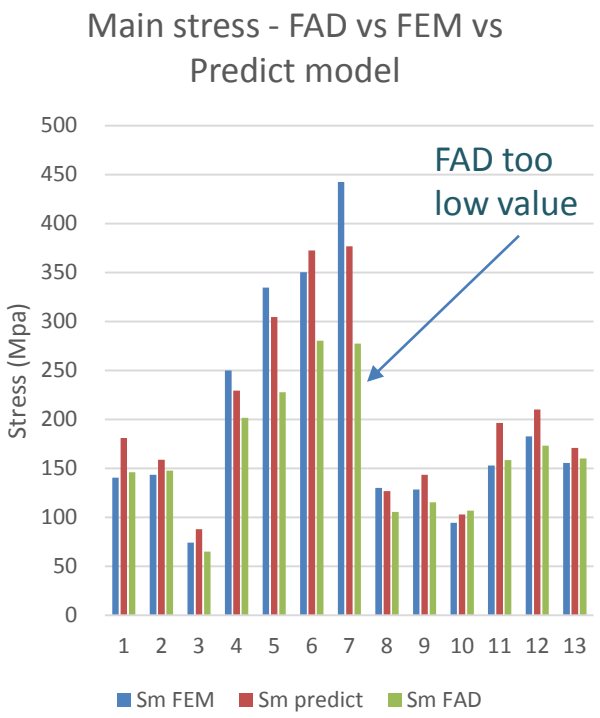


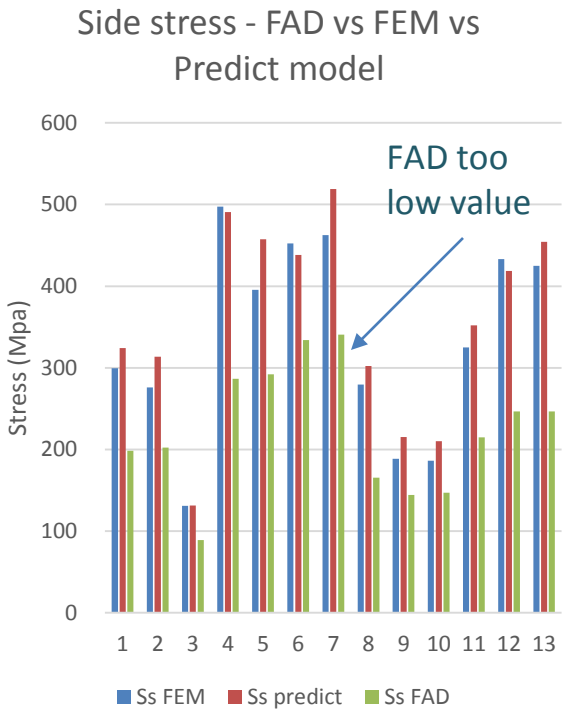
** R^2 value of test data increases from 0.36 to 0.65 ➔ better than original 2nd order model!*

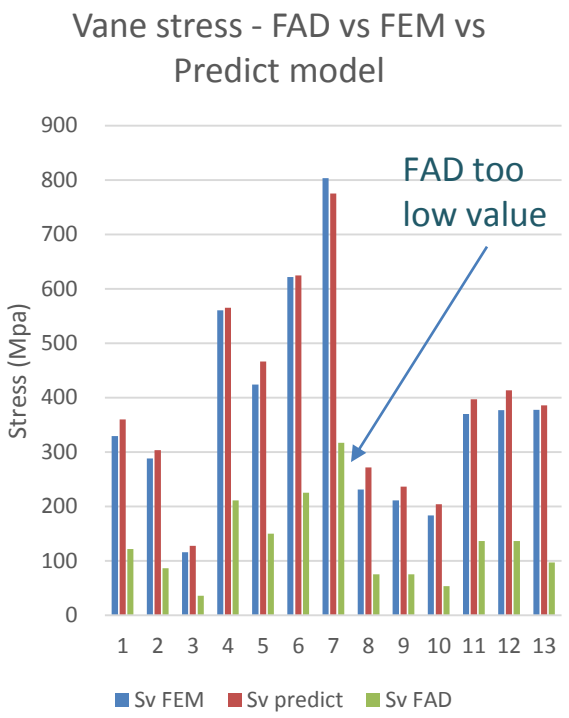
** Accuracy is not very high. All predicted values stay within +/-20% of true values.*

6. Modeling result

Stress result – FAD vs FEM vs Predict model







** FAD stress value is lower than FEM value, especially vane stress value.*

** Predict model value is close to FEM value ➔ high prediction accuracy!*

7. Conclusion

Conclusion:

- 2nd order polynomial regression model can accurately predict stress value of vane, side and main within +/-10%.
- Weight and GD2 of impeller can also be predicted with similar model with very high accuracy, within +/-5%.
- Frequency can be modelled using modified 2nd order polynomials with medium accuracy, within +/-20%.

Future works:

- Addition parameters such as ribs number and rim can also be modeled to check their effect to impeller's stress.
- A more sophisticated model can also be used to improve accuracy of prediction model, such as using neural network modeling.