Innovative methodology dedicated to the CERN LHC cryogenic valves based on modern algorithm for fault detection and predictive diagnostics

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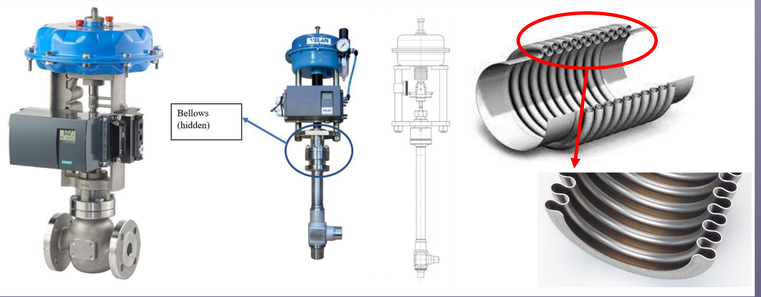
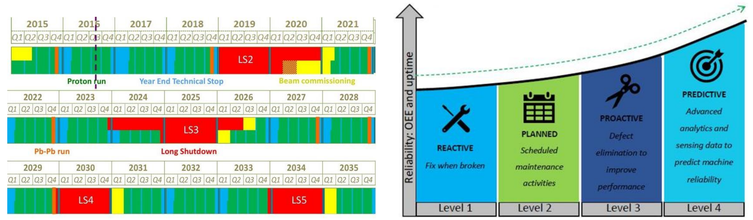
Abstract

The European Organization for Nuclear Research (CERN) cryogenic infrastructure is composed of many equipment, among them there are the cryogenic valves widely used in the Large Hadron Collider (LHC) cryogenic facility. At present time, diagnostic solutions that can be integrated into the process control systems, capable to identify leak failures in valves bellows, are not available. The authors goal has been the development of a system that allows the detection of helium leaking valves during normal operation using available data extracted from the control system. The design constraints (inaccessibility to the plants, variety of valve models used) has driven the development towards a solution integrated in the monitoring systems in use, not requiring manual interventions. The methodology presented in this article is based on the extraction of distinctive features (analysing the data in time and frequency domain) which are exploited in the next phase of machine learning. The aim is to identify a list of candidate valves with a high probability of helium leakage. The proposed methodology, which is at very early stage now, with the evolution of the data set and the iterative approach for the test phase presented in the last paragraph, is aiming toward a cryogenic valves targeted maintenance in the LHC cryogenic accelerator system.

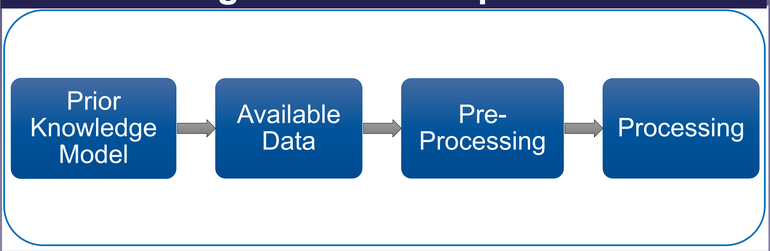
Cryogenic Valves



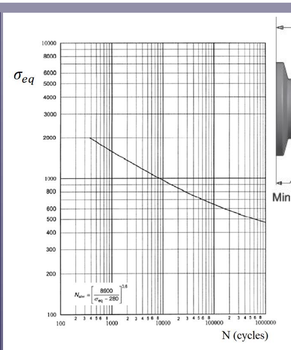
Reasons

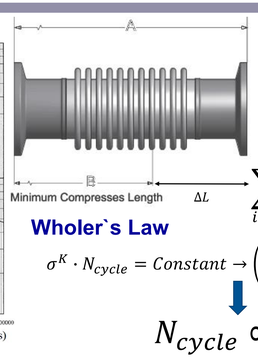


Algorithm development



Prior knowledge





Hooke`s Law

$$F = -k \cdot \Delta L \rightarrow \sigma = \frac{-k \cdot \Delta L}{S}$$

Palmgren-Miner`s rule

$$\sum_{i=1}^{K} \frac{n_i}{N_i} = Damage\ parameter$$

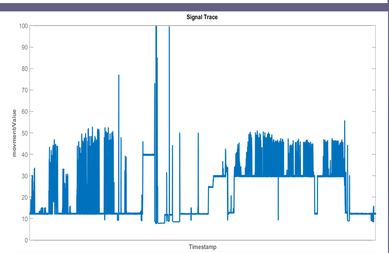
Wholer`s Law

$$\sigma^K \cdot N_{cycle} = Constant \rightarrow \left(\frac{-k \cdot \Delta L}{S}\right)^K \cdot N_{cycle} = Constant$$

$$N_{cycle} \propto 1/\Delta L$$

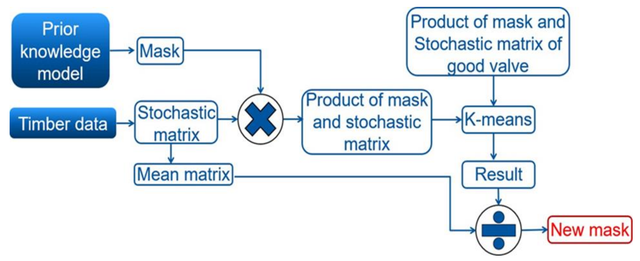
Available data

Extracted SIPART positioner data



Trace of the movements

Pre Processing

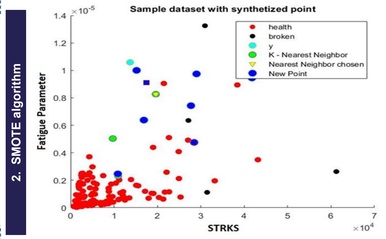


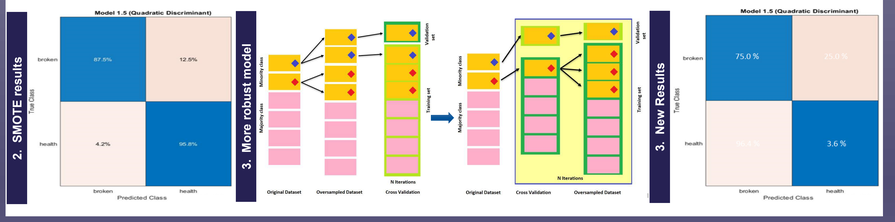
Processing: Machine Learning Models

1. Cost Sensitive Learning

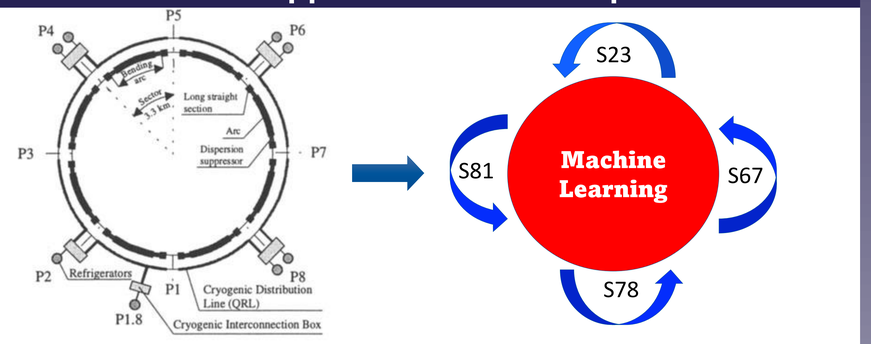
	TPR(%)	TNR (%)	CR	New TPR (%)	New TNR (%)
Linear Discriminant	50	98.2	6	62.5	96.4
Quadratic Discriminant	75.0	96.4	3	87.5	95.8
Subspace Discriminant	50	98.2	23	75	94.0
Linear SVM	25.0	98.2	9	75.0	96.4
Medium SVM	25.0	100	23	62.5	95.2
Coarse Gaussian SVM	0	99.4	18	75	93.4
Kernel Naive Bayes	75.0	95.8	9	87.5	92.2

2. SMOTE algorithm





Iterative approach for the test phase



Conclusions

The authors present in this paper an innovative solution for fault detection of cryogenic valves bellows installed in the CERN LHC accelerator. The development was focused to produce a solution able to be easily applicable to the data from the existing cryogenic control system. The solution consists of a pre-processing step in which a features extraction is performed and a ML phase for the data drive modelling. The dataset, for the training and validation step, is composed of recorded data characterized of 174 valves by different features. Several classifiers were validated and best performances, exploiting the oversampling of broken valves, were reached by means of Quadratic Discriminant. The Quadratic Discriminant model has accomplished good performances both with oversampling and cost-sensitive learning technique. The presented results were obtained using an unbalanced dataset of heterogeneous types of bellows-sealed control valves. The work presented in this manuscript will constantly evolve when more dataset become available to improve the training and validation steps and perform the iterative test step.

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