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Gulati, Karan Mr.; Basandrai, Keshav Mr.; Tiwari, Shubham Mr.; Kamat, Pooja Prof.; and Kumar, Satish Dr., "Predictive maintenance of bearing machinery using simulation- a bibliometric study" (2021). *Library Philosophy and Practice (e-journal)*. 5110.

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Predictive maintenance of bearing machinery using simulation- a bibliometric study

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ABSTRACT

Modelling is a way of constructing a virtual representation of software and hardware that involves a real-world device. We will discover the behaviour of the system if the software elements of this model are guided by mathematical relationships. For testing conditions that may be difficult to replicate with hardware prototypes alone, modelling and simulation are particularly useful, especially in the early phase of the design process when hardware might not be available. Model-based approach in MATLAB-Simulink can be useful for predictive maintenance of machines as it can reduce unplanned downtimes and maintenance costs when industrial equipment

breaks. Through this bibliometric paper, we carefully investigated the previously done research with the help of a number of papers from the Scopus Database. An overall analysis of the papers has been carried out to identify the extent of research done in this domain and understand the nature of the research work carried out considering the evolution of various predictive maintenance strategies being developed in recent years.

Keywords: Predictive Maintenance, Bearing, Fault Detection, MATLAB, Simulink, Data-Driven Model

1. INTRODUCTION

Bearings are important components of a reduced friction mechanical system that allows for rotating or linear motion. It would be nearly impossible to design and operate a mechanical or electro-mechanical system without bearings. There is a wide range of bearings depending on the applications-ball bearing is the most common shape bearing used in daily applications, for example in motor vehicles and industrial machines. Having well-lubricated bearings in your machines plays a critical function. A simple ball bearing consists of individual bearing components which include a specific number of balls, an inner and outer ring and a retainer. Fig. 1 shows the components of a simple ball bearing.

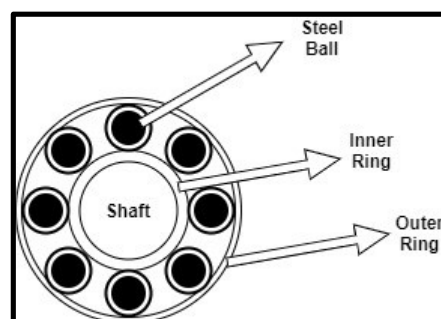


Fig 1: Components of a simple ball bearing

Like other mechanical parts, for different reasons too, bearings can suffer from premature failure or housing defects. It is important to distinguish between the bearing longevity determined by load fatigue during operating speeds and the service life of the bearing, which for different purposes defines the bearing uptime before a bearing is decommissioned. Some of the most common bearing defects are given below:

1. **Inner and Outer Race Fit:** Inner race fit problems may be due to a loose fit that can rotate and damage the inner race on the shaft, or a too tight fit that can strip internal clearances and strain the bearings. Inner and outer race flaws. Also, outer race fit issues are close. A too tight fit will have the same impact as previously mentioned, a too loose fit will cause the bearing to have high vibration and fretting.
2. **Cage defects** - The vibration and effect of a bearing's moving surfaces under high-pressure conditions also affect its cage life.
3. **Bearing misalignment** - During machine assembly, misalignment is a common cause of noise from the bearing, increased torque, and poor output in general.
4. **Inadequate lubrication**- The main cause of the failure of the bearing is insufficient lubrication. Issues include too much lubricant; too little lubricant; the use of the wrong lubricant; the combination of incompatible lubricants; inappropriate intervals of lubrication; the use of old, deteriorated grease or oil; and water pollution. Fig. 2 shows the analysis of Bearing problems occurring in machinery.

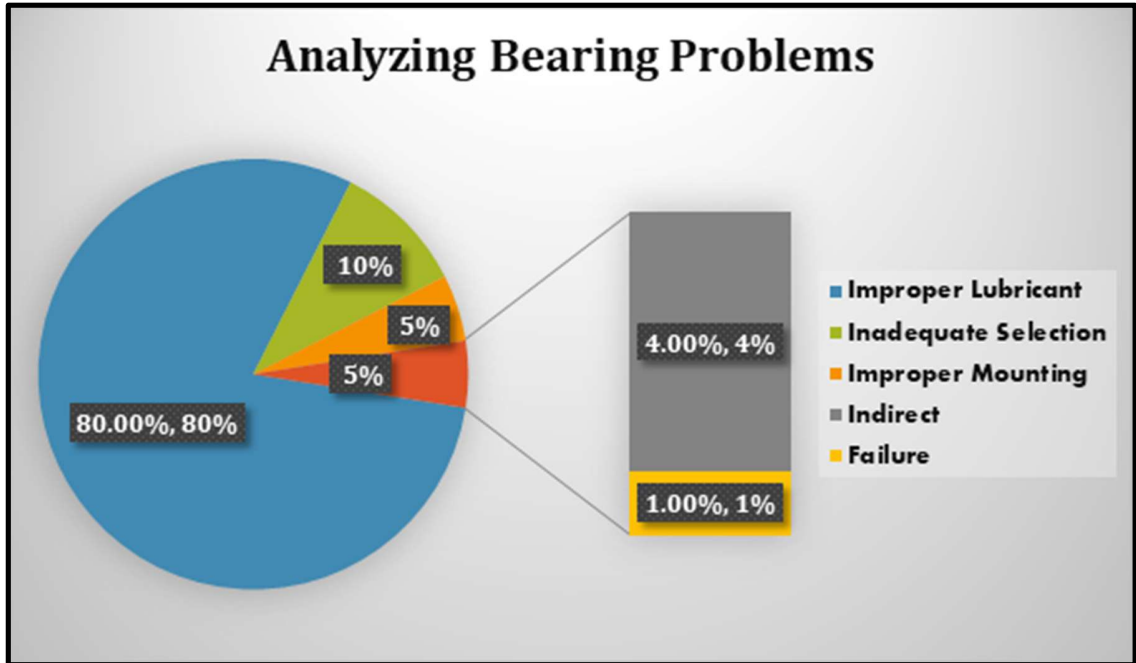


Fig 2: Analyzing Bearing Defects

1.1 Predictive Maintenance

In order to estimate when maintenance should be completed, predictive maintenance techniques are developed to help evaluate the condition of in-service equipment. This strategy offers cost savings over routine or time-based preventive maintenance, because only when warranted are tasks performed. It is therefore considered to be condition-based maintenance carried out as indicated by an item's deterioration status estimates. Data Driven Predictive Maintenance is very useful and effective as it helps in reducing the downtime, optimize spare parts inventory. Preventive maintenance plays an important role in maximizing the equipment lifetime. A simulation of the bearing machinery can be prepared in MATLAB-simulink which then helps us to create datasets from the simulation model itself. Data sets consist of both working data as well faulty data of the bearing machines. Using these synthetic datasets we can improve upon the data from the physical machines. Fig. 3 shows the applications of Predictive Maintenance.

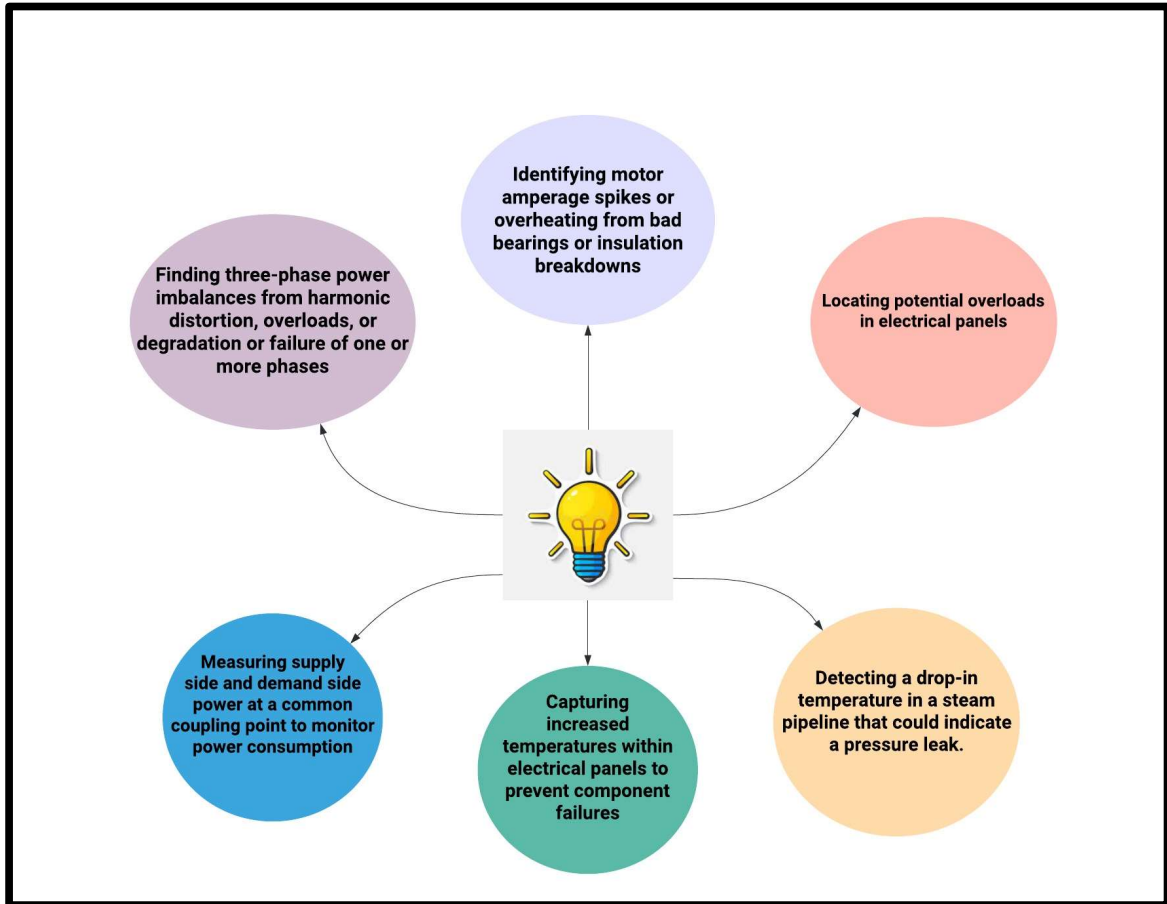


Fig 3: Applications of Predictive Maintenance

2. LITERATURE RESEARCH AND REVIEW

The paper titled “ Fault diagnosis of roller bearing using parameter evaluation technique and multiclass support vector machine” was published in AIP Conference Proceedings Journal in 2017[1]. It signifies Parameter Evaluation technique in SVM classification to achieve maximum accuracy in determining the type of fault occurring in the bearing machines and also predicting the overall health of the bearing in the machines. In the same year, there were multiple research articles and papers were published in Science Direct, IEEE,

Intech Open Journals which involved the condition monitoring of machinery like compressors and power converters using MATLAB. In 2019, A paper titled “Ball bearing fault diagnosis using wavelet transform and principal component analysis”[2] was published in AIP Conference Proceedings Journal. The paper explained the wavelet transform and PCA for acquired vibrations signals for roller bearings. There were multiple papers published in Science Direct Journal and International Journal of Pattern Recognition and Artificial Intelligence in 2019 involving Fault Detection using K-means Clustering titled as “Acoustic Fault Analysis of Three Commutator Motors”[3] and “Bearing Fault Diagnosis Based on VMD-SVD and Fuzzy Clustering”[4]. These research papers explained fault diagnosis done by combination of K-means and Fuzzy Clustering which uses decomposition methods to obtain fault characteristics of bearing with maximum accuracy. We Identified the evolution of practices and algorithms being implemented in the field of Fault Diagnosis in machinery involving the use of bearings including simple bearings roller bearings and ball bearings. The following flow diagram shows us how the technology and algorithms to understand fault detection have evolved throughout the span of the last four years (2017-2020) in the domain of machine maintenance strategies involving bearings. Fig. 4 shows the evolution in Fault Detection Strategies

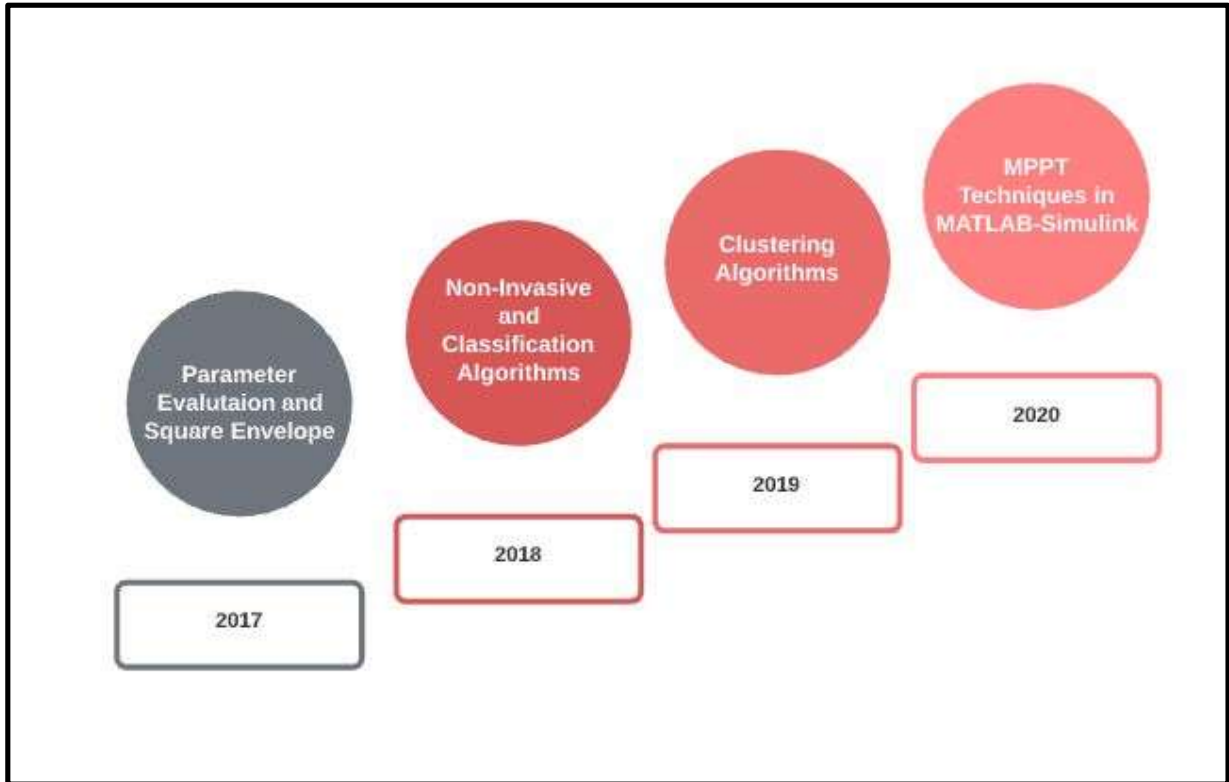


Fig 4: Evolution In Fault Detection Strategies

After complete research and review, it can be concluded that the machine is normally accompanied by strong nonlinear and non-stationary vibrations during the operation of mechanical systems, and the failure of the rolling bearing would further cause the unwanted vibration of other components, so that the measured vibration signals are typically mixed with or submerged in other parts' vibration signals and background noise[5][6][7]. This creates the need to detect and diagnose these faults for efficient functioning of all the mechanical components of a machine[8].

3. PRELIMINARY DATA COLLECTION:

3.1 Search Procedure

Scopus Database, Web of Science Journal, Science Direct, ResearchGate, Google Scholar, SciELO are the most common publication databases. To access this database, there are two forms, free access and paid access. For the present analysis, the paper considers the Scopus and Web of Science database. Scopus contains comprehensive reviews and judgments on the field technical, medical, social sciences research papers. The Web of Science is the most strong research engine in the field of technical, medical, social sciences. The world's most global citation database is responsible.

3.2 Keywords

Different keywords have been used as search conditions in the Scopus Database. The master and primary types of keywords related to Predictive Maintenance Of Machinery used are given below in Table 1:

Table 1: List of keywords used in this bibliometric study

Primary Keyword	"Bearings"
Secondary Keyword	"Predictive Maintenance" OR "Fault Detection" OR "MATLAB" OR "Simulink"

The Master Keyword "Bearings" along with "Predictive Maintenance" or "Fault Detection" gives us a total of 2592 papers which have been published in various journals. There have been a lot of previous papers published in the field of "Predictive Maintenance" and "Fault Detection" of various Machinery[9][10][11]. However, "Bearings" as a master keyword has helped in making the research more specific to bearing machinery. Fig. 5 depicts the word cloud of keywords used in the related research.

The names of journals, authors, types of papers, etc. are extracted from all articles published until 2020 from the available literature in the Scopus database, including several years of publications, for the following review.

3.4 Analysis Of Citation Count By Year

The mechanism by which an article's impact or "quality" is measured by counting the number of times it is listed by other writers in their work. Invoices of citation analysis that count the number of times an article is cited by other works to measure the influence of a publication or author graph show the total count of citations per year for these research papers starting from 2016 till 2021. Fig. 6 shows the analysis of citation count by year.

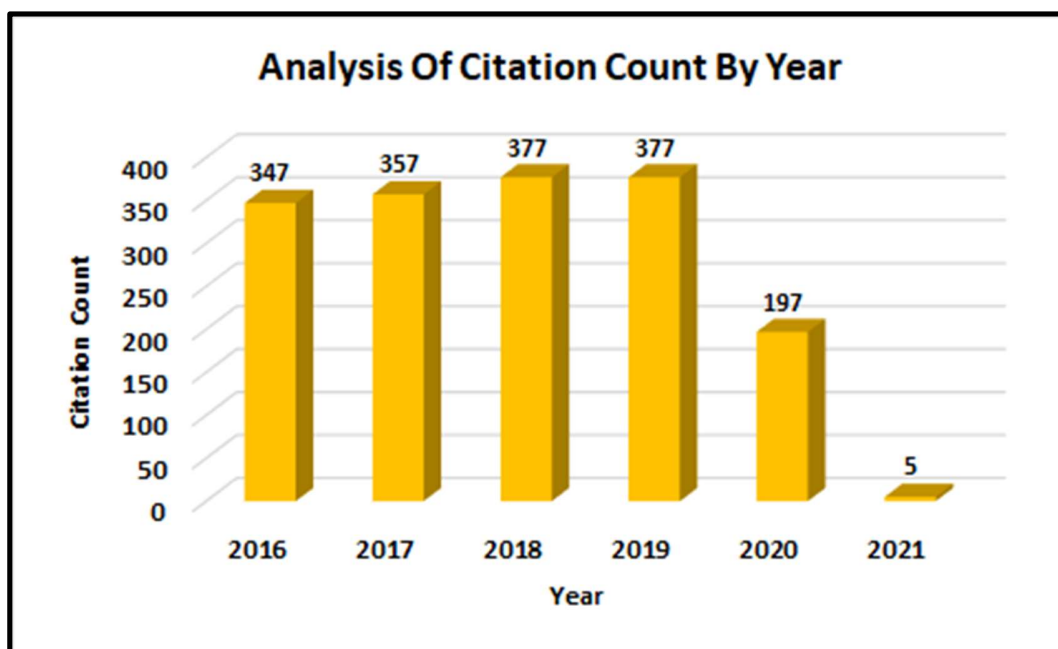


Fig 6: Analysis of Citation Count By Year

Source: <http://www.scopus.com> (accessed on 20th OCT, 2020)

3.5 Document Analysis By Affiliation

The industry or government agency shall request that a specified research project be carried out with defined goals and objectives. The research project is often carried out on the basis of an agency's successful request for funds [12]. The analysis is expected to result in a deliverable product or report of commercial significance to industry. Researchers should expect peer-reviewed publications to be able to generate a detailed research report. Fig. 7 shows the document analysis by affiliation.

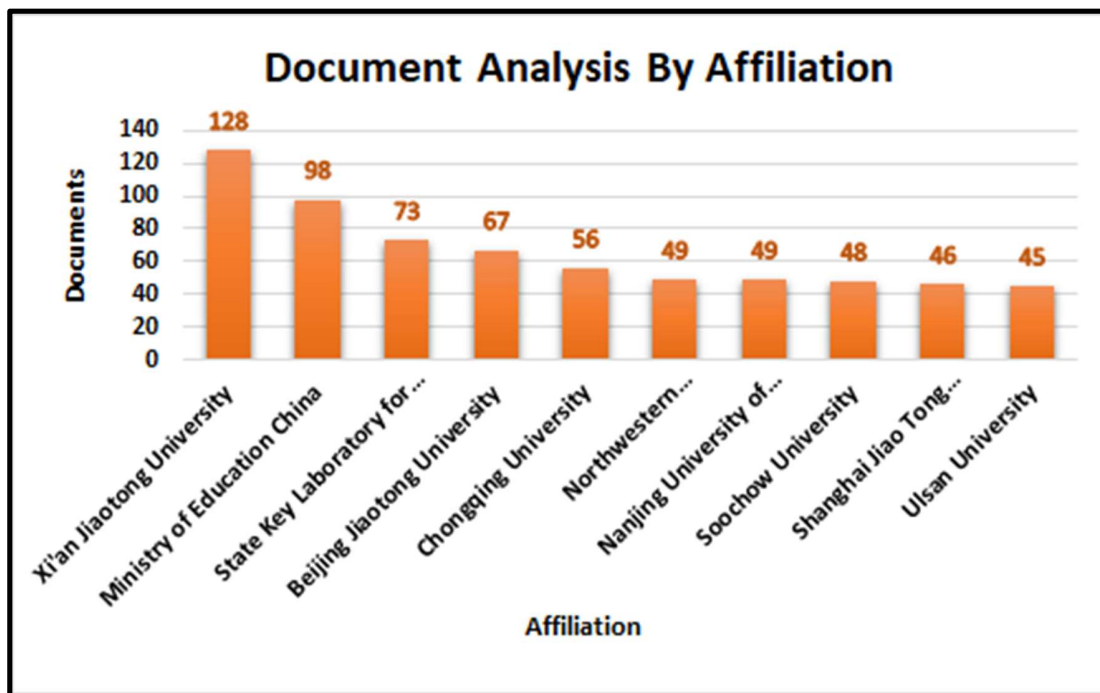


Fig 7: Document Analysis By Affiliation
 Source: <http://www.scopus.com> (accessed on 23rd OCT 2020)

3.6 Document by country or territory

A Number of Research papers have been published in journals and been presented in research conferences. The following graph gives us the information on the contribution done in respective countries, wherein clearly China is ahead in terms of total research articles and papers being published. Fig. 8 shows the documents by country or territory.

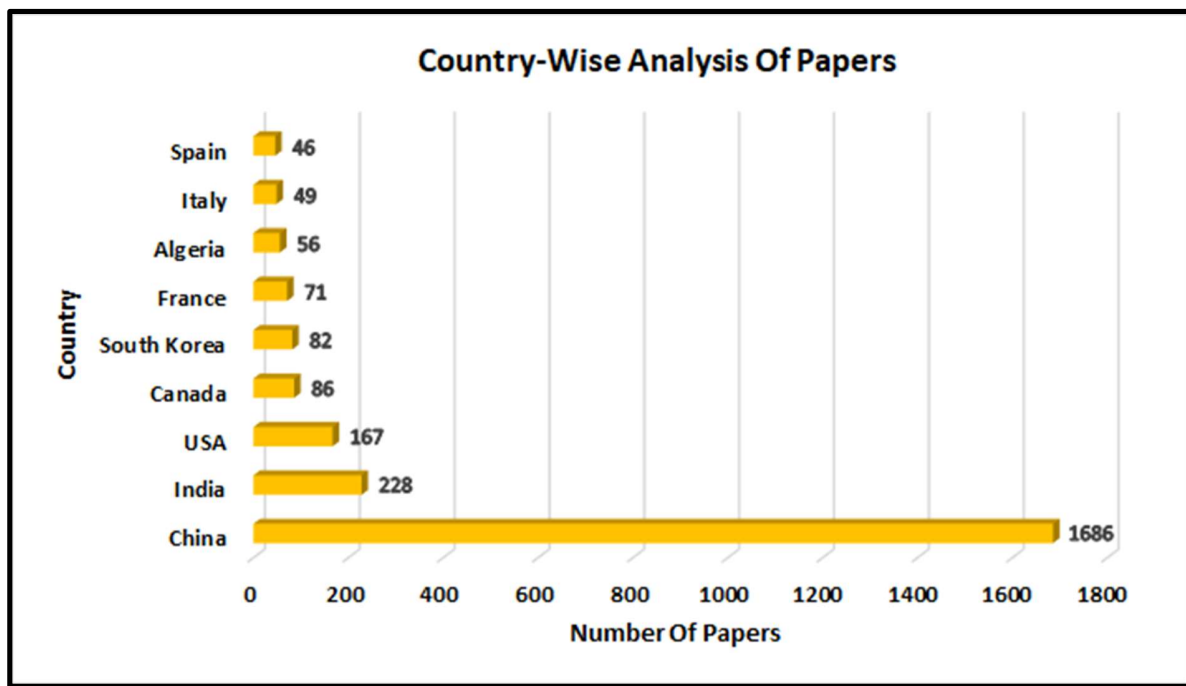


Fig 8: Documents by country or territory

Source: <http://www.scopus.com> (accessed on 23rd OCT 2020)

3.7 Document by subject area

The Following figure shows a thorough comparison of different subject areas with the data evaluated for “Bearing” and “Predictive Maintenance”. From this figure, it is noted that maximum research in computer science and engineering is carried out. It is also observed that biochemistry, genetics and molecular biology have performed at least part of the study. Fig. 9 shows the documents by subject area.

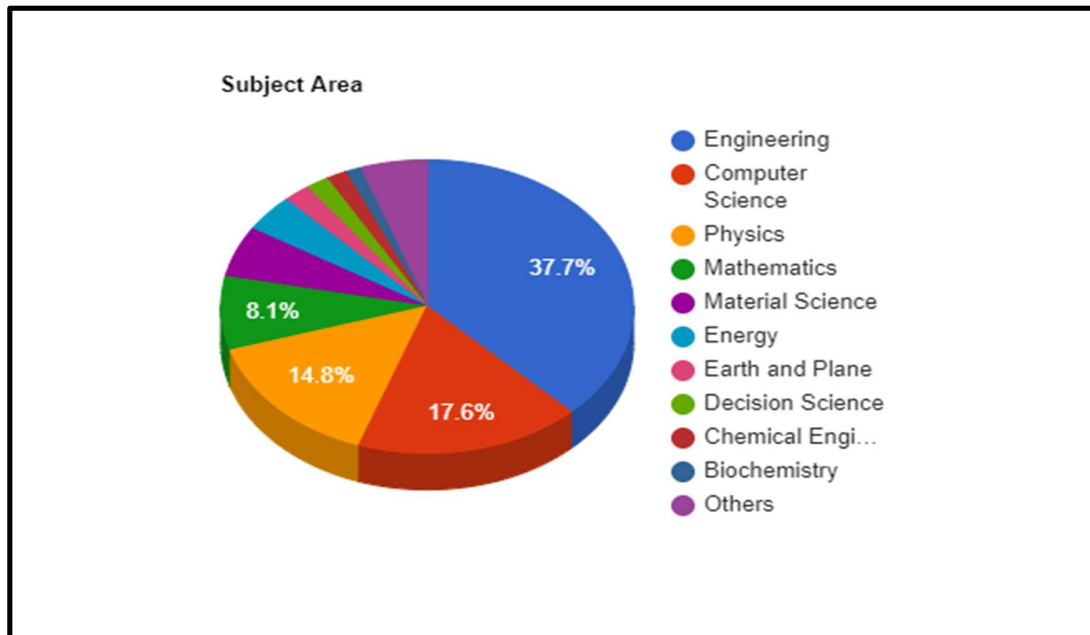


Fig 9: Documents by Subject Area

Source: <http://www.scopus.com> (accessed on 23rd OCT 2020)

3.8 Analysis Of Papers by year

The following table gives an overview of the number of documents collected in each year by the scopus database. The Analysis of these documents from the year 2016 till 2021 shows that the maximum number of documents for the research areas were collected in the year 2019 and the least number of documents were collected in 2021. Fig. 10 helps in analysing the count of papers by year(2016-2021).

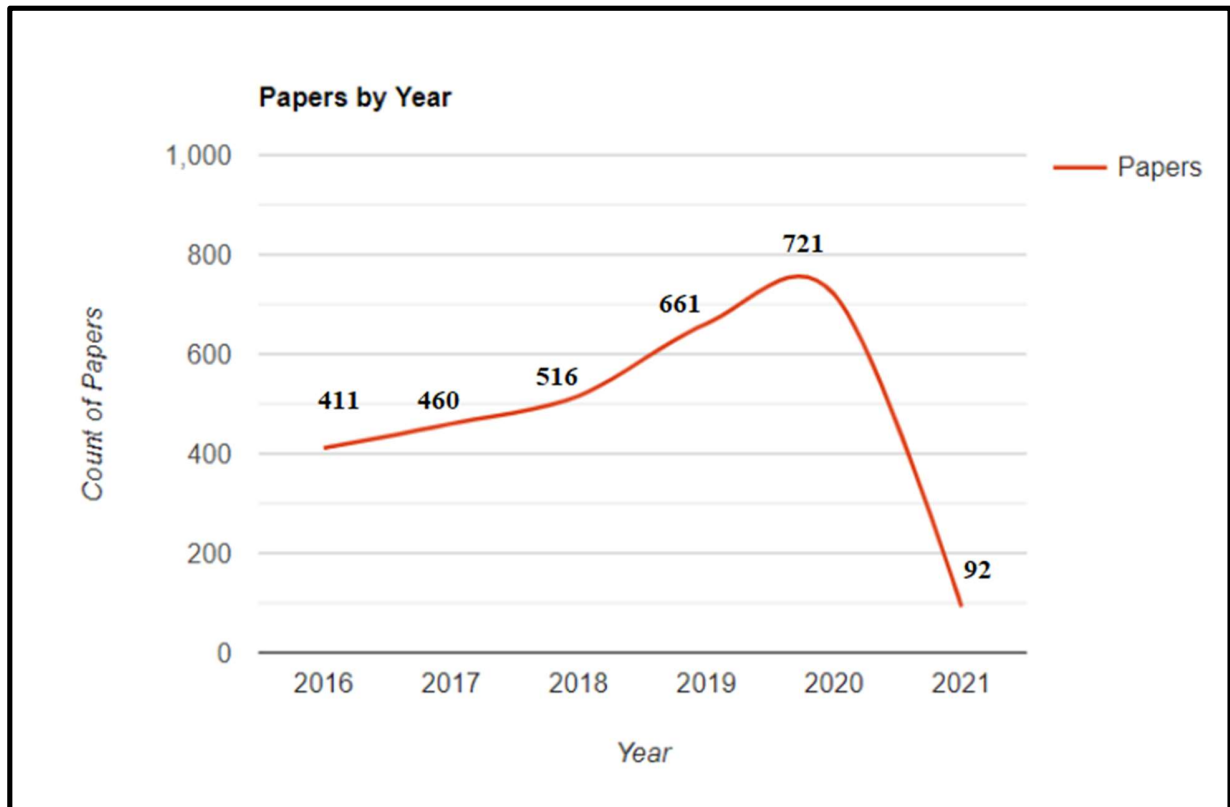


Fig 10:Papers by year

Source: <http://www.scopus.com> (accessed on 23rd OCT 2020)

3.9 Document by author

The following bar graph shows the contributions to the Scopus Database by each author individually. The number of documents submitted by Kim, J.M was maximum in number. KimJ.M contributed to 31 documents in the Scopus Database. The minimum number of contributions of documents was done by Jia,M. Fig. 11 shows the count of documents by author.

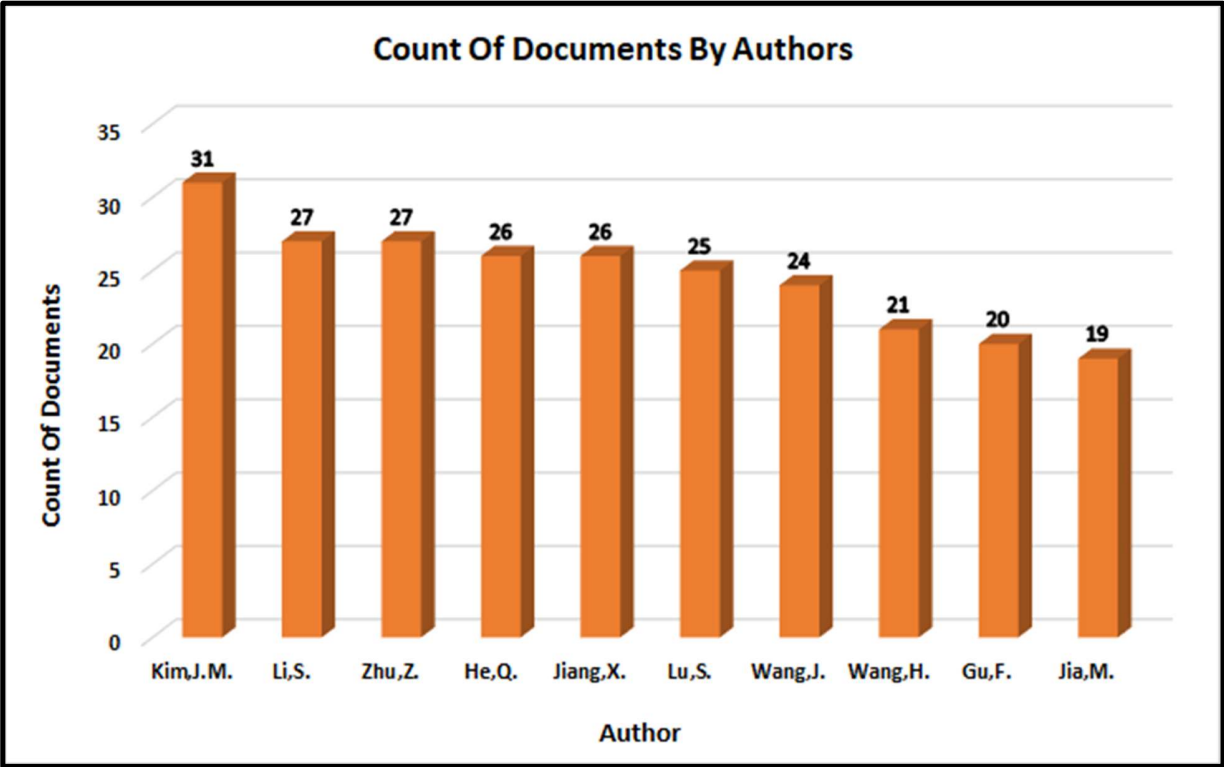


Fig 11: Count Of Documents by Authors

Source: <http://www.scopus.com> (accessed on 23rd OCT 2020)

3.10 KEYWORD ANALYSIS

Some of the popular keywords are enlisted. The accuracy in keywords gives you the exact targeted count in a significant area of research. First ten keywords enlisted in Table 2 by keeping in mind those publications on Fault Detection. Table 1 shows the first top 10 keywords on fault detection.

Keywords	Number of Publications
Fault Detection	2100
Failure Analysis	1375
Roller Bearing	1021
Bearing (Machine Parts)	543
Signal Processing	467
Bearing Fault Diagnosis	442
Vibration Analysis	428
Feature Extraction	427
Condition Monitoring	392
Fault Diagnosis	859

Table 2: First top ten keywords on Fault detection

Source: <http://www.scopus.com> (accessed on 23rd OCT, 2020)

3.11 Top Funding Agencies Available

Funding agencies are entities that provide services, initiatives and people in a particular region with grants, scholarships, or other types of support. Non-profit organisations, private foundations, or government offices may be supporting agencies. As a general rule, the purpose of a funding agency is to encourage excellence or to foster interest in a specific topic, such as renewable energies, the climate, social work or medical innovation[13][14]. The following figure gives us the top ten funding agencies available in the research area. Fig. 12 shows the document by funding sponsor.

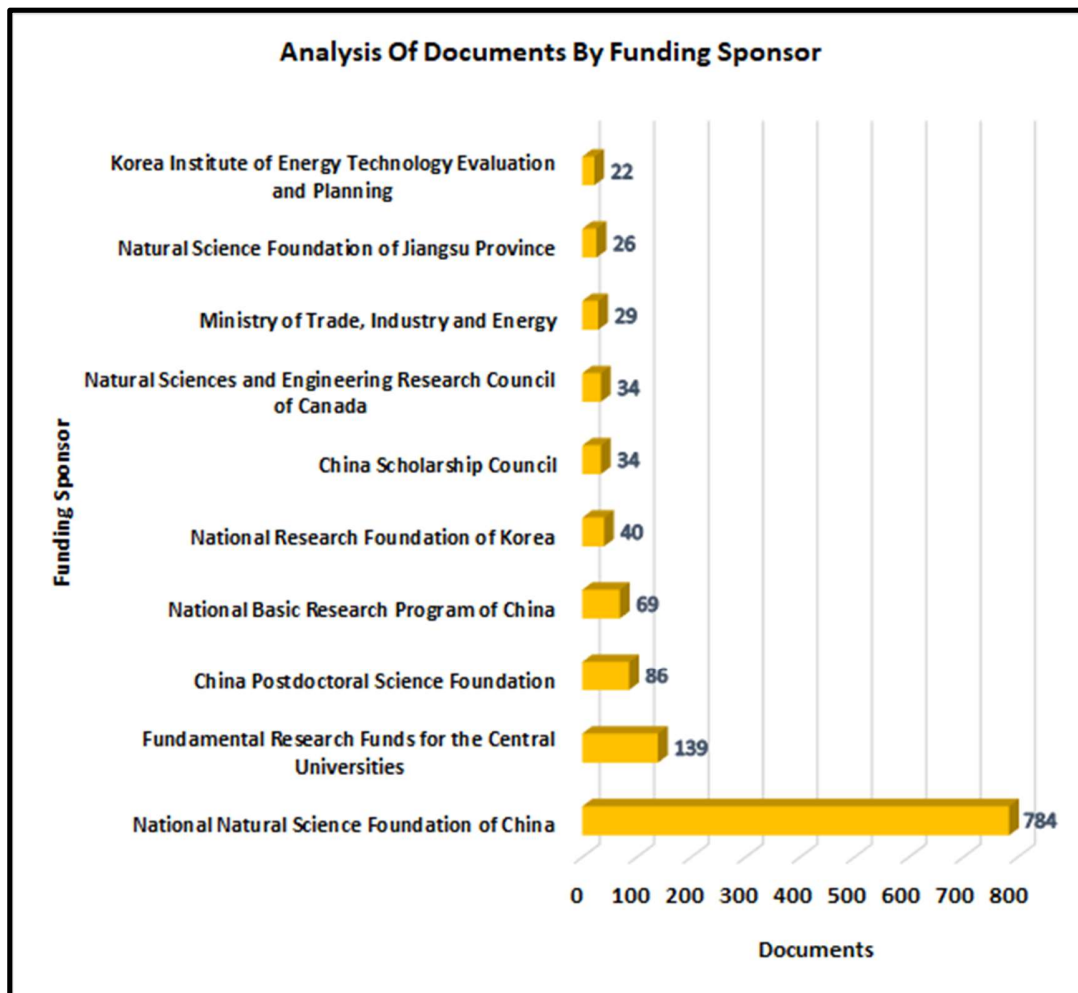


Fig 12: Documents by funding sponsors

Source: <http://www.scopus.com> (accessed on 23rd OCT, 2020)

3.12 Document By Type Percentage

The scopus database has document types including Data Papers, research articles, Conference papers and some other set of certified documents. The following pie chart

gives us the percentages of each of such document types. The maximum number of documents are of type Articles. Fig. 13 documents by type percentage.

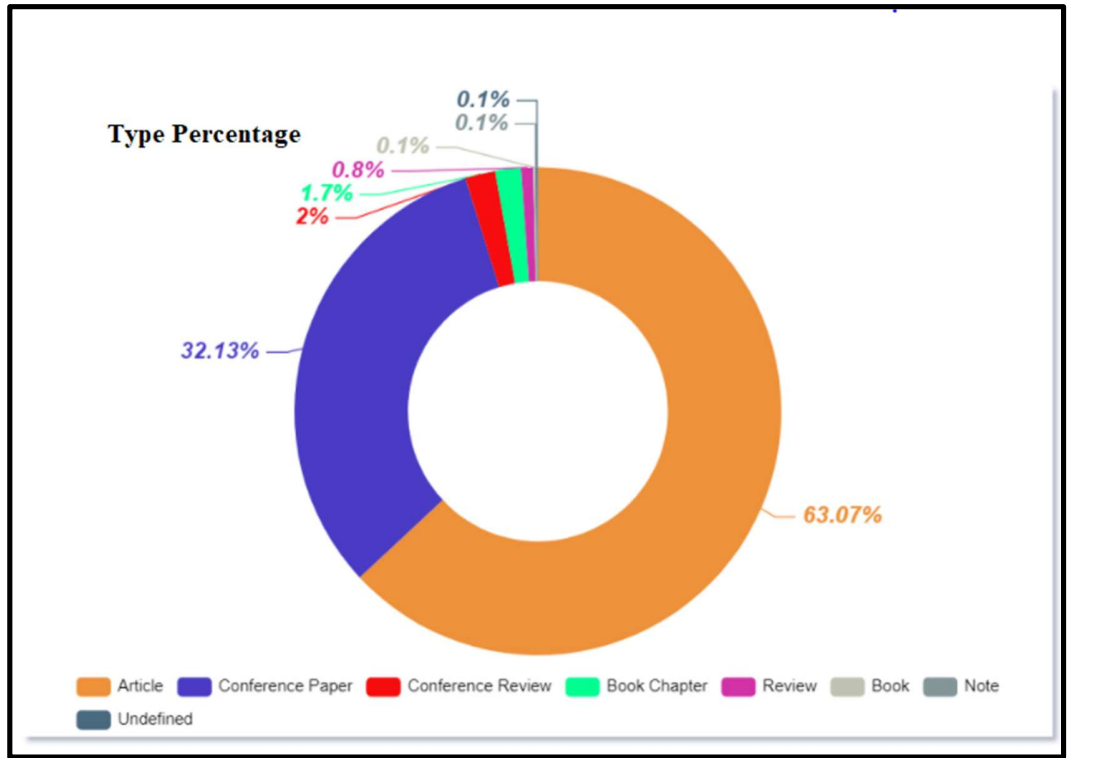


Fig 13: Documents by Type Percentage

Source: <http://www.scopus.com> (accessed on 23rd OCT, 2020)

3.13 Author Count With Document Type

The comprehensive Research from Scopus Database includes a different category of documents having individual or same authors depending on the requirements. The following graph indicates that the Documents of “articles” type has been written by a maximum number of authors for this particular set of scopus research databases. This visual also signifies that only some of these researchers have written papers for research conferences. Fig. 14 shows the count of authors associated with each document type. Fig. 14 author count with document type.

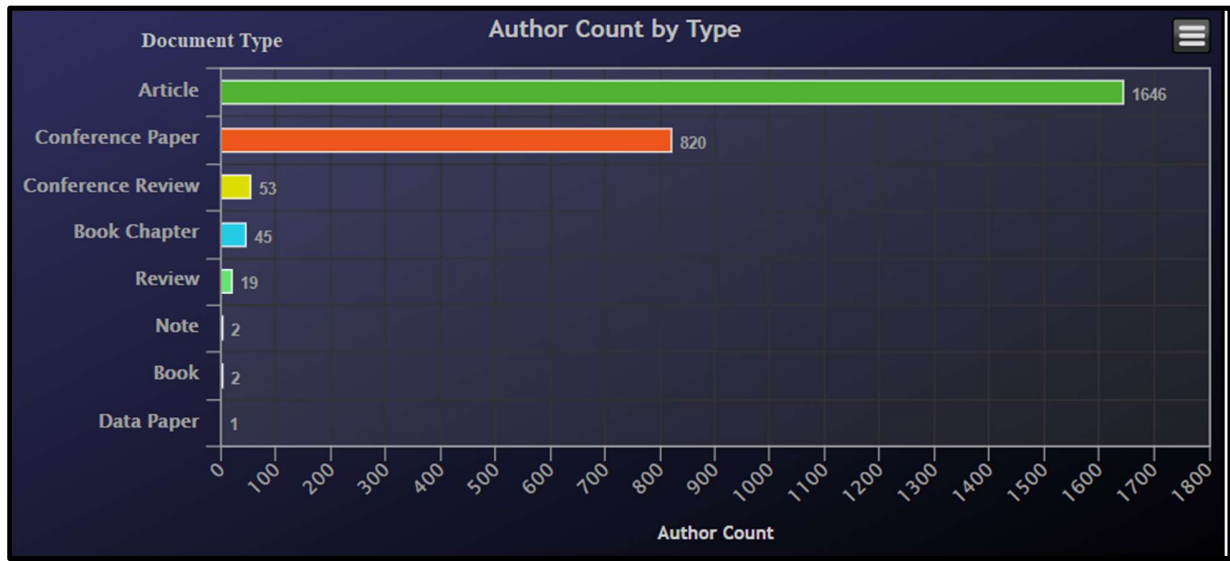


Fig 14: Author Count With Document Type

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.14 Number Of Publications Vs Citations Per Year

The importance of research articles being published and cited is very huge when it comes to carrying out bibliometric research analysis. The following line graph is of great importance for comparing and contrasting between the number of papers being published vs the number of being cited at the same time. This comparison is done for each year starting from 2016 till 2021. In the year 2019, the publication count and the citation count was at par with each other whereas in other years there were certain diverging trends when it comes to publication count and citation count. Fig. 15 shows the number of publications vs citations per year(2016-2020).

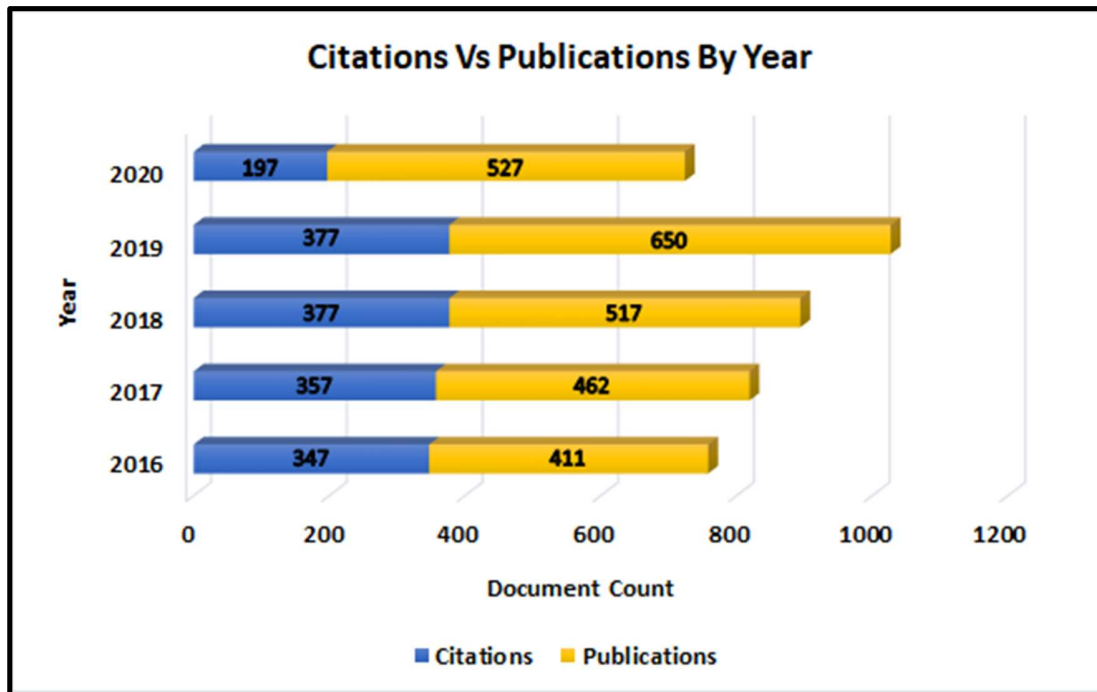


Fig 15: Number Of Publications Vs Citations Per Year

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.15 Documents By Language

It is clearly visible from the following graph that the maximum number of research papers have been published in “English” Language with some of the research work done in Chinese also. However for our bibliometric research, we have considered only papers published in English only. Fig. 16 shows the documents by language.

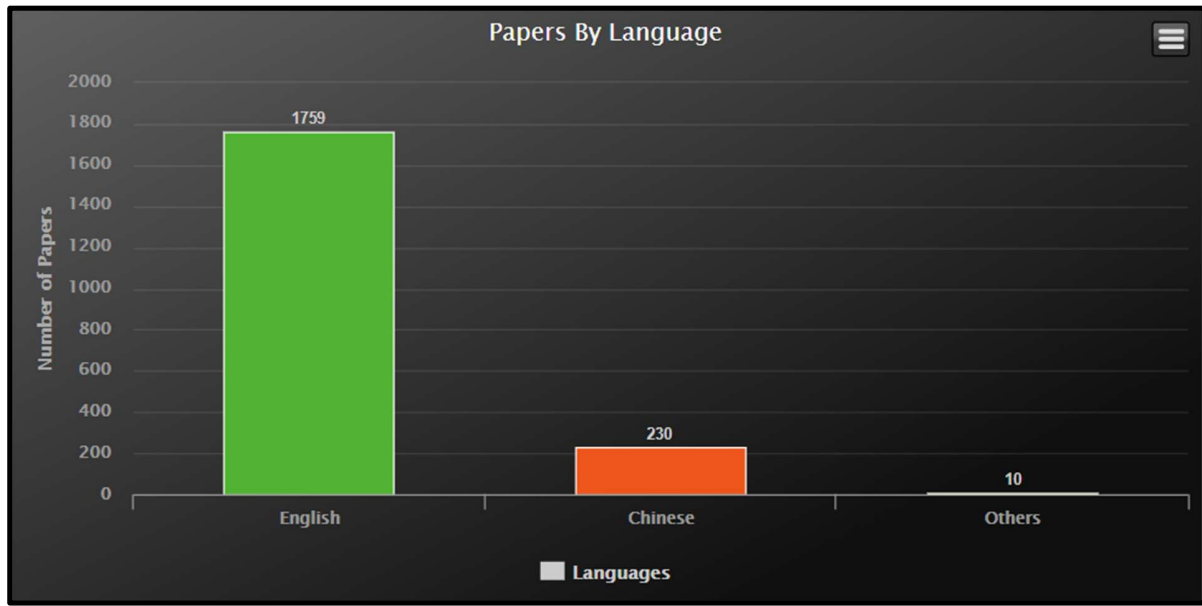


Fig 16: Documents By Language

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.16 Analysis Of Papers Published By Country

Below the figure is a geographical world map that provides the countries highlighted on the basis of popular published papers. The aim is to know that the reliability of research is more than just a specific geometric area. It is confirmed from the map that the most number of research papers were published in China. Therefore the researchers are part of China and were predominantly responsible for providing the papers in Scopus Databases. Fig. 17 shows the analysis of papers by country.

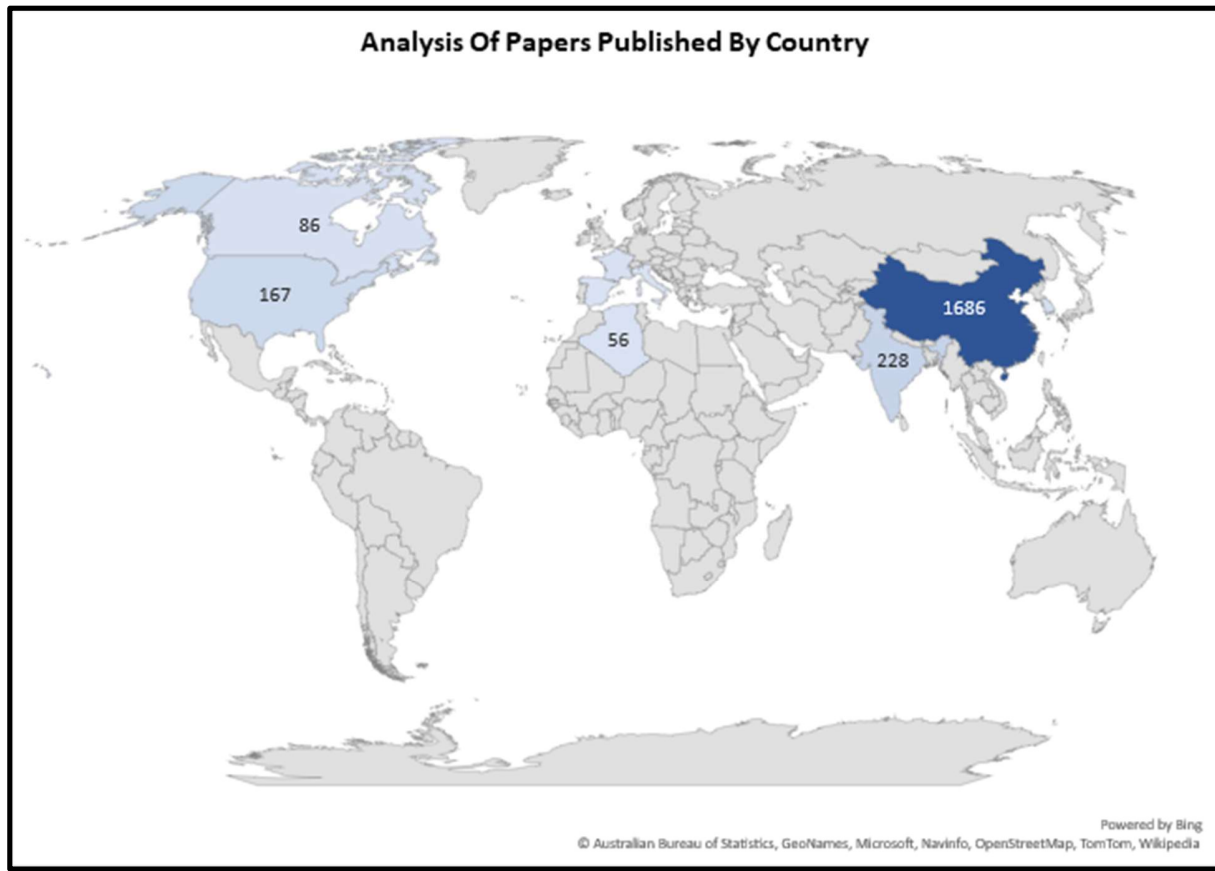


Fig 17: Analysis Of Papers By Country

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.17 Documents By Author

This is the chart of network analysis focused on the combination of keywords with Scopus source names. Circles in the map reflect keywords used in extracted document source names. The wider the circle higher the level of keyword incidence. The Links connecting the circles signify the distance between two keywords. If the relation size is smaller, the correlation between the keywords would be more extensive. The same colour represents the cluster formed by keywords. Maximum & Minimum number of authors per document for this graph is 25 & 5 respectively. Total number is 318. Fig. 18 shows the documents by authors.

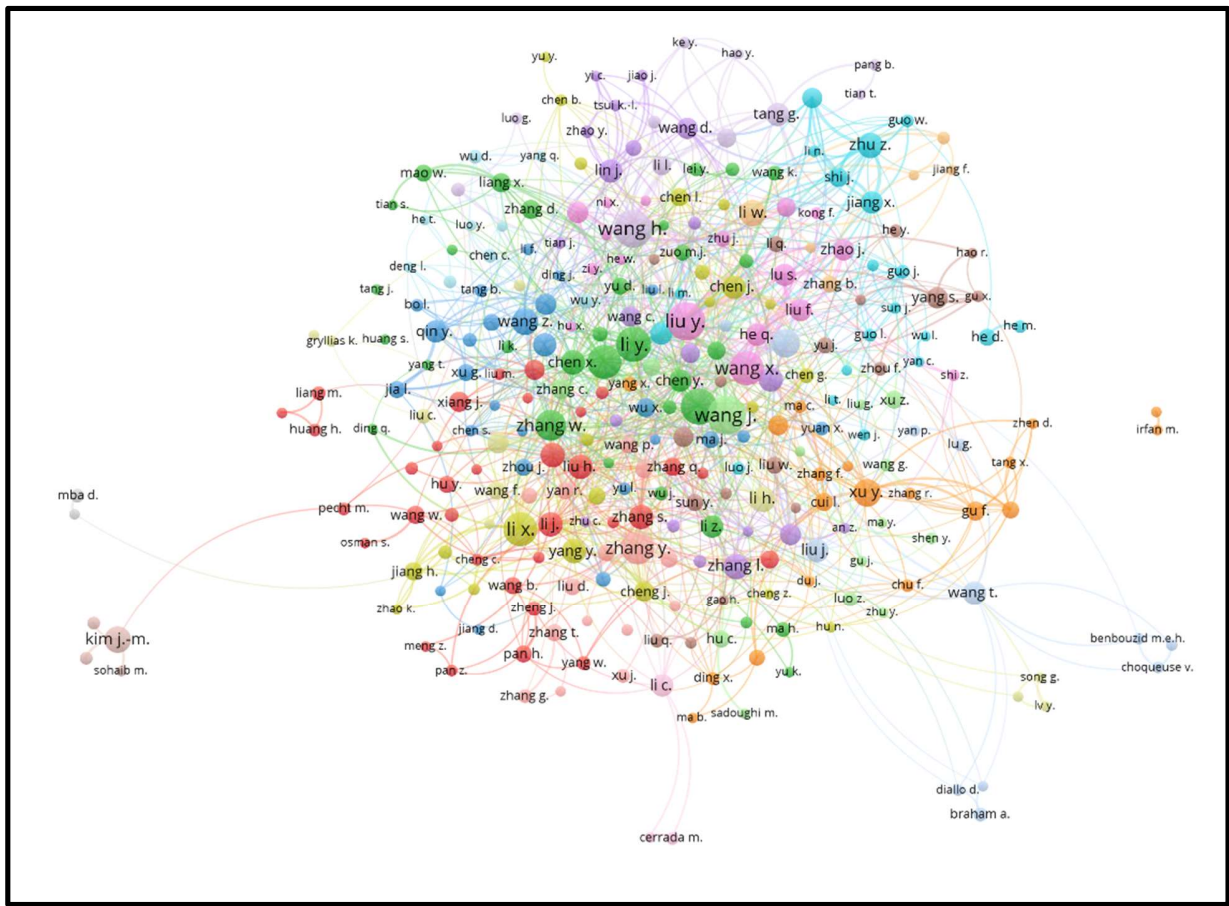


Fig 18: Documents by Authors

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.18 Documents By Organisations

This is the chart of network analysis focused on the combination of keywords with Scopus source names. Circles in the map reflect keywords used in extracted document source names. The wider the circle higher the level of keyword incidence. The Links connecting the circles signify the distance between two keywords. If the relation size is smaller, the correlation between the keywords would be more extensive. The same colour represents the cluster formed by keywords. Maximum & Minimum number of organisations per document for this graph is 25 & 5 respectively. Total number is 57.

Fig. 19 describes the documents by organisations.

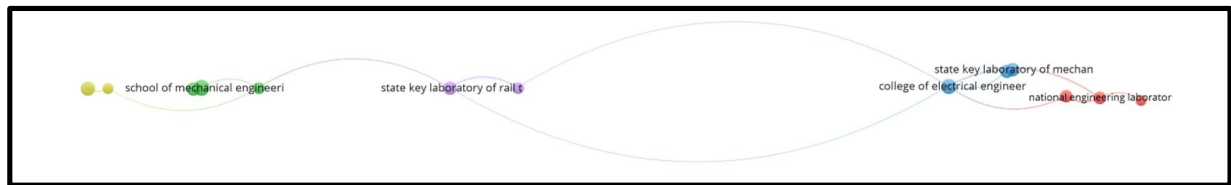


Fig 19: Documents by Organisations

Source: <http://www.scopus.com> (accessed on 2nd Nov, 2020)

3.19 Documents By Countries

This is the chart of network analysis focused on the combination of keywords with Scopus source names. Circles in the map reflect keywords used in extracted document source names. The wider the circle higher the level of keyword incidence. The Links connecting the circles signify the distance between two keywords. If the relation size is smaller, the correlation between the keywords would be more extensive. The same colour represents the cluster formed by keywords. Maximum & Minimum number of authors per document for this graph is 25 & 5 respectively. Total number is 40. Fig. 20 shows the documents by country.

Given the progressive implementation of new technology and standards in plants, they offer unparalleled opportunities to boost OEE and reduce maintenance costs. Nonetheless the large investments made in industrial maintenance projects also need substantial justification. With the development and advancements of latest technology, a lot of industries are moving towards an effective maintenance strategy revolving around Predictive Maintenance[15]. As IOT technology is growing to be useful in Industry 4.0, we have witnessed a revolution in maintenance management using sensors and wireless communication. The sensors have the ability to connect to Machine components and gather information about its proper functioning and getting maintenance plans beforehand. However, there lies a good level of improvements in technological domains in Predictive Maintenance.

Conclusion

Bibliometric analysis focusing on the content of fault detection, particularly fault detection using various algorithms and its documentation studies is required. Bibliometric research allows researchers to gain a better understanding of the possible topics of research and the holes in research. This bibliometric survey for the identification of bearing faults helped the authors recognise the different factors that could be considered when being considered conducting their research in this area. Through their citation analysis, the authors were able to classify the prospective journals for their further experimental publications and the keywords that could be used for carrying out further literature surveys. Bearing fault detection has a lot of scope for research with the evolution of simulation based predictive maintenance approaches for the various day to day machinery.

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