Modern Tribology Research: Identification of Seminal Publications

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***Abstract* - In this study, the seminal publications in the modern tribology research are identified using a newly developed scientometric method called "Reference Publication Year Spectroscopy (RPYS)" based on the cited references. The Science Citation Index – Expanded (SCI-E) is used as data source. The study focuses on frequently cited most important papers published after 1966. The result suggests that important papers for the development of tribology research have been published only after the introduction of the term "tribology" in 1966 which could easily help the researchers to overview their area of research.**

***Keywords*: Bibliometrics, Citation Peak, CRExplorer, Reference Publication Year Spectroscopy (RPYS), Seminal Publications, Tribology**

I. INTRODUCTION

Recently, Marx et al. (2014) [1] introduced a scientometric method "Reference Publication Year Spectroscopy (RPYS)" to reveal the important historical publications in a specific research field. The RPYS method is based on analyzing the early references cited frequently in the publications of a specific research field in terms of the publication years of the cited references. Subsequently, Thor et al., (2016) [2] introduced a new tool "CitedReferencesExplorer" which is an improved version of the older one. The program CRExplorer (freely available at www.crexplorer.net) simplifies the identification of key publications by enabling the user to work with the graph and the list of the CRs; both show the CRs per year and the two representations are related.

The term *tribology* was coined by Jost in the year 1966 which was defined as the science and technology of two interacting surfaces in relative motion and of related subjects and practices. It is a highly multidisciplinary field which incorporates a number of disciplines namely mechanical engineering, material science, mechanics, surface chemistry, and surface physics. According to a report of the South African Institute of Tribology, tribology is a property of matter and the second most important field of study of material property after gravity (Elango and Rajendran 2015 [3]; Elango et al., 2016 [4]).

Historical roots of a specific subject or an author's work or on a specific journal have been identified using the RPYS method. Barth et al. (2014) [5] identified the origin and historical of Higgs boson research using a segmented regression analysis with RPYS method. Leydesdorff et al. (2014) [6] applied the RPYS method to the historiography of iMetrics based on the articles published in the three journals Scientometrics, Journal of the American Society for Information Science and Technology (JASIST), and the Journal of Informetrics (JoI). Marx and Bornmann (2014) [7] traced the origin of scientific legend "Darwin Finches" using the RPYS method. Comins and Hussey (2015) [8] identified landmark research contributions to the field of global positioning systems using the RPYS method. Elango et al. (2016) [4] identified the historical roots of tribology research using the RPYS method. Haunschild et al. (2016) [9] analyzed the seminal publications on DFT. Khasseh et al. (2016) [10] examined the most important historic works written in the area of knowledge management (KM) and found that the ratio of articles to books among the whole documents detected by RPYS was 2-13 which could direct us to the point that the channel for transformation of information in KM is more focused on books than on articles.

Currently, the RPYS method is being used to identify the historical most important publications in a specific research field. However, there is no study to identify the contemporary important publications.

The major aim of this study is to identify the seminal publications in the modern tribology research using RPYS method. This study is based on the cited references provided by the authors in the literature on the tribology research. There is a major problem in processing the cited references with lack of standardization and variants of CRs (see Table 1). Thor et al. (2016) [2] provided a partial solution for this problem in the new tool *CRExplorer*.

Table 1 – Example of CR variants

Author	Variants of CRs
Archard (1953)	ARCHARD JF, 1953, J APPL PHYS, V14, P891
	ARCHARD JF, 1953, J APPL PHYS, V14, P981
	ARCHARD JF, 1953, J APPL PHYS, V24, P18
	ARCHARD JF, 1953, J APPL PHYS, V24, P481
Majumdar (1991)	MAJUMBAR A, 1991, J TRIBOLOGY, V1, P1
	MAJUMDAR A, 1991, J TRIBOL-T ASME, V113, P1
	Majumdar A., 1991, ASME, V113, P1
	Majumdar A., 1991, Transactions of the ASME. Journal of Tribology, V113

II. METHODOLOGY

The bibliographic data for the tribology field is obtained from the Science Citation Index - Expanded (SCI-E, Thomson Reuters). The study is mainly concerned with the analysis of contemporary publications cited frequently as the seminal publications of modern tribology research. The bibliographic records on tribology are retrieved with the following search strategy (Elango et al., 2015 [11]; Elango et al., 2016 [4]): **tribolog* OR "tribosyst*" OR "tribo-syst*" OR "tribo-chem*" OR "tribochem*" OR "tribotechn*" OR "tribo-physi*" OR "tribophysi*"*. The publications up to 2014 are retrieved and downloaded as plain text. Then the text file is uploaded in the CRExplorer software for further analysis. The referenced publication years are set between 1966 and 2014.

III. RESULTS

A general overview of the data set used in this study is provided in Table 2 which shows that 42% of cited references were published after the term tribology was introduced in the year 1966. This result supports the keywords selection to retrieve the bibliographic data related to tribology research.

Table 2 – Overview of the data

Item	**#**
Number of publications	24086
Publication Period	1953-2014
Total number of cited references	577472
Number of cited references after 1966	246158 (42%)

Referenced Publication Years from 1966 to 2014

There are three peaks exhibited between 1966 and 2014 (after the introduction of the term "tribology" in 1966) in a span of 49 years. As the deviation from the median in Figure 1 shows the highest peaks appear in 1987, 1992 and 2000. The result suggests that important papers for the development of tribology research have been published after the introduction of the term "tribology" in 1966.

Jost report [12] is an important reference publication in the field of tribology. However, this report is being used to show the importance of tribology towards economic development only [13], [14].

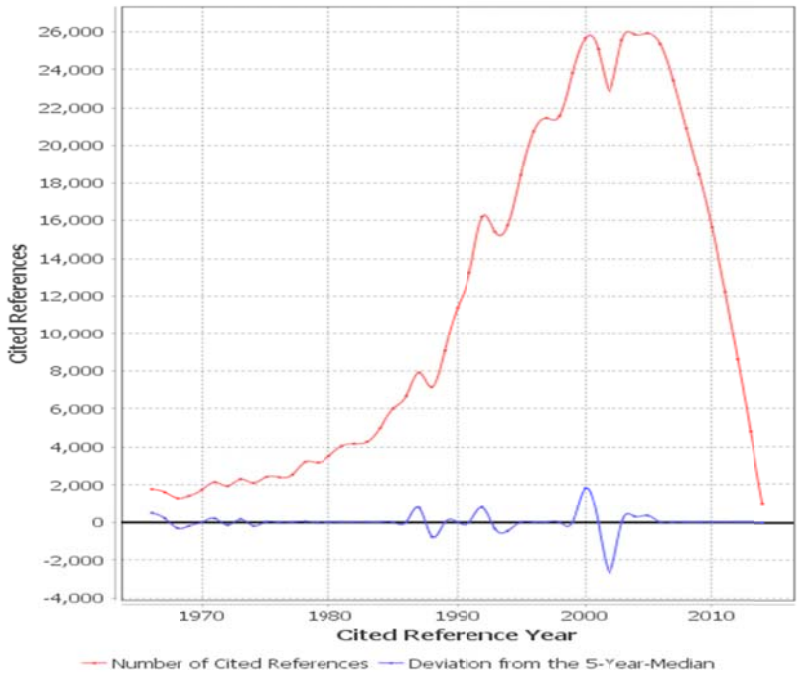

Figure 1 – Referenced publication years between 1966 and 2014

Table 3 – Most frequently cited publications during 1966-2014		
RPY	**TCR**	**Frequently Cited Publications**
1987	7919	257 refer to Mate C M (1987). Physical Review Letters, 59: 1942.
		165 refer to Lim S C (1987). ActaMetall Mater, 35: 1343.
		145 refer to Tomizawa H (1987). ASLE Tr., 30: 41
		105 refer to Tsai H, J VacSci Tech A, 5: 3287.
1992	16197	903 refer to Oliver W C (1992). Journal of Materials Research, 7:1564.
		253 refer to Hutchings I M (1992). Tribology Friction
		123 refer to Israelachvili J, Intermolecular Surface
		103 refer to Moulder J F, hdbxrayphotoelectr
		103 refer to Tenne R (1992). Nature, 360: 444.
2000	25653	340 refer to Ferrari A C (2000). Physical Review B, 61: 14095.
		301 refer to Leyland A (2000). Wear, 246: 1.
		181 refer to Bahadur S (2000). Wear, 245: 92.
		140 refer to Voevodin (2000). Thin Solid Films, 370: 224.
		124 refer to Musil (2000). Surface Coatings & Technology, 125: 322.
		108 refer to Chhowalla (2000). Nature, 407: 164.
RPY = Referenced Publication Year, TCR = Total Cited References		

In the 19th century and the beginning of the 20th century the peaks in a RPYS are generated by a single highly cited publication in tribology (Elango et al., 2016 [4]). After the introduction of the term “tribology” in the year 1966, more than one publication adds impact to generate a peak (Table 3). Thus, we discuss more than one publication in a peak in the following:

The first peak in 1987 refers to the following four articles:

Mate, et al (1987) [15] used an atomic force microscope to measure lateral forces and nanometer scale friction, atom-by-atom which revolutionized the study of friction at atomic length scales. The observations on friction and measurement on atom-by-atom are published in this landmark paper. Subsequently a steady increase of literature on FFM since 1987 is noticed.

Lim et al. (1987) [16] have constructed a wear mode map and wear transition map, to predict the type and severity of wear to explain the changes in wear rate for a wide range of operating conditions.

Tomizawa (1987) [17] reported the results of friction experiments on Si_3N_4 and SiC and found that the above materials dissolved in water at room temperature.

The discussion by Tsai (1987) [18] reveals the preparation of carbon as a thin film material and its layers as a protective overcoat for a thin-film magnetic media for higher density storage.

The second peak in 1992 refers to the following five publications:

The analysis technique used by Oliver (1992) [19] provides procedures for establishing a contact area at peak load after accounting for the curvature, determination of the depth and the indenter shape.

The book entitled “Tribology: Friction and Wear of Engineering Materials” authored by Hutchings (1992) [20] covers both the mechanical and materials aspect of tribology apart from providing a scientific and practical foundation towards a thorough understanding of the phenomenon of friction, wear and lubrication.

The book “Intermolecular and Surface Forces” Isralachvilil (1992) [21] is very useful for colloid and surface science which is a general up-to-date treatise. This is a classic reference for the molecular origins of tribological processes.

The “Handbook of X-ray Photoelectron Spectroscopy” authored by Moulder, et al. (1992) [22] is an updated version of the previous edition. This handbook serves as a guide and reference for users on physical electronics XPS systems in terms of identification, interpretation, quantification and calibration of XPS spectra systems.

The first inorganic nanotubes and fullerene-like nanoparticles, made of WS_2 were discovered by Tenne, et al. (1992) [23]. WS_2 nanotubes have a tubular structure similar to carbon nanotubes, built up by one or more sets of triple layers which contain a metal layer of tungsten sandwiched between two layers of sulphur atoms. However, nanotubes have high mechanical strength and very low friction coefficients under certain sliding conditions.

The third peak refers to the following six articles:

Ferrari and Robertson (2000) [24] discussed the relationship between the Raman spectra and DLC film structure. They found that Raman spectroscopy is a suitable method to determine the sp2 bonding structure of carbon film.

Leyland and Matthews (2000) [25] discussed the significance of elastic strain to failure and fracture toughness in determining tribological behavior. They only introduced the deposition of metallic nano-composite coatings to provide superior wear resistance.

Bahadur (2000) [26] examined the effect of counterface roughness and the growth of transfer film which lead to the mechanism of wear due to tribological behavior.

Musil (2000) [27] reviewed the development of hard coatings from a titanium nitride film through super lattice coatings to nano-composite coatings and super hard coatings. This correlated the nanocomposite coatings to the structure.

To provide optimum performance for material in any environment, durability, reliability and wear resistance can be increased considerably by nano-composite coating or chameleon tribological coating developed by Voevodin (2000) [28].

The deposition method suggested by Chhowalla (2000) [29] allows the formation of the low-friction layer directly onto the components instead of dispersing the nanoparticles into oil, which can lead to adverse clogging. According to Chhowalla (2000), the low-temperature nature of the process also allows it to be used on top of hard, magnetic thin films to give a low-friction layer.

CONCLUSION

In this study, the software routine CREpolorer is used to analyze the seminal publications in the modern tribology research. The results show that RPYS has not only the potential to identify the historical publications but also to identify the contemporary seminal publications which were effectively used in the field of modern tribology. As a result of this study, the seminal publications which have been cited more frequently by tribology researchers could be identified. However, we cannot act on the assumption that all important publications can be identified by RPYS (Barth et al., 2014) [4]; further expert opinion in this field is needed to complete the data and information as required.

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