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DETERMINATION OF GLOBAL RESEARCH ACTIVITIES IN MECHANICAL ENGINEERING VIA BIBLIOMETRIC ANALYSIS

This study reveals significant and emergent research topics in the field 'engineering, mechanical' through bibliometric analysis of articles indexed in Web of Science (WoS) from 1997 to 2016. Publications under consideration (219,191 articles) were examined using quantitative and qualitative methods to evaluate general information about publications; evolution of research topics by keyword analysis; performance of countries, research centers and journals; and international collaborations. There was a threefold increase in number of articles throughout the period. The publications were related to 35 WoS categories; and mechanics and thermodynamics were dominating ones. International Journal of Heat and Mass Transfer was the leading journal in the field. The USA and China were outstanding countries of the field. Collaboration between these countries corresponded to 6.57% of all collaborative publications. Industrialized and developing countries dominated research activities in the field. Indian Institute of Technology was the leading research center due to number of publications. The results showed that heat transfer, finite element method, friction, wear, simulation, and fatigue are important topics of the field. There is an upward trend in research related to nanofluids, microchannel, phase change materials, and carbon nanotubes.

1. Introduction

Mechanical engineering is one of the oldest disciplines that concerns in application of physical sciences and mechanical systems. As an applied science, mechanical engineering researches phenomena in an empirical way and utilizes

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theoretical knowledge for industrial applications. The field concerns closely not only mechanical engineers but also other engineering disciplines such as civil, metallurgy, aerospace, electrical, and biomedical. Due to its broad point of interest, scientists of the field conduct collaborative studies involving many other disciplines. Most of these conducted studies end up with a scientific publication. These publications either are a solution for a current problem or shed light on the future studies. Thus, evaluation of the publications in the field is important both to reveal the current situation and to specify the research needs for the future.

Bibliometric analysis, firstly used by Pritchard [1], is a common tool to reveal the research trends by means of qualitative and quantitative analyses. Besides content and citing studies, analysis of author addresses, keywords, language of publication, title, and journals are instruments of bibliometric analysis [2]. Bibliometric analysis has a vital role in determining whether a topic is worth to be researched. It is also important to decide what research should be done and/or supported by the governments and funding organizations.

Researchers, institutions, publishers, and governments care about which topic is worth to research because of limited resources. In this context, some scientific indicators were proposed to measure influence of agents. For instance, Hirsch devised the h-index to specify both quantity and significance of a researcher's publications [3]. Later on, the h-index was calculated to indicate the performance of countries [4]. Another example is the Impact Factor (IF) which is used to assess importance of a journal [5]. Moreover, Garfield stated that analysis of keywords could be used to determine hot spots in a particular field [6]. Author keywords and words in title of publications are popular in bibliometrics recently [7].

Authors have already used bibliometric analysis in a particular field such as civil engineering [8], respiratory medicine [9], management [10] or special topics like nanotechnology [11], solid waste [12], dioxins [13] that concerns more than one discipline. However, such a study, analyzing research activities in the field of mechanical engineering, does not exist and a systematic research in the field will help to use research funds efficiently. In this study, a bibliometric analysis was carried out to reveal significant and emergent research topics in the field 'engineering, mechanical' based on articles indexed in Web of Science (WoS) from 1997 to 2016.

2. Materials and method

A Bibliometric analysis was performed based on articles collected from WoS database, a well-regarded scientific citation indexing service and one of the most preferred databases to analyze research activities [14]. An advanced search was applied that oriented WoS 'engineering, mechanical' category and limited to articles published during the period 1997-2016 where the Journal Citation Reports (JCR) exists. The search was done in March 2017 and query results were downloaded as 'Full Record'. The data were composed of 219,191 articles, 21,939 proceedings papers, 1 book chapter and 18 retracted publications. Only articles were considered to analyze research activities during the period. A data manipulation algorithm was developed based on Python programming language and publication details were analyzed within this program. Publications of interest were assessed in the sense of evolution of research topics by means of keywords, productiveness of countries and research centers, collaboration of countries, and diffusion of journals. Time-dependent observations were done at four-year intervals. To highlight recent research activities, findings gathered from whole period inspected were compared with the last period (2013–2016).

Author keywords are one of the instruments mainly used in bibliometric analysis [7]. For this kind of studies, results may be erroneous due to nonstandard use of keywords. Some keywords are not unique because of differences between British and American English. Besides, authors may prefer singular or plural forms of words. In this study, a method based on Python's built-in function was applied to deal with the variations of keywords. Firstly, keywords beginning with the same three letters were clustered into groups. Then, the method designated a ratio between 0 and 1 by comparing two words and grouped the words having a higher value than the threshold under one word. Due to uncertainty of the limit to say whether words are the same, the threshold was determined empirically as 0.850 after several examinations. For example, the ratio of 'Finite Element (FE) Method'/'Finite Element Method' pair was equal to 0.894, whereas 'CNC'/'CMC' pair was 0.667. Also, common abbreviations used in keywords were added to the relevant group.

Nearly 4% of publications (8511) did not have address info and some of others were mistyped. Thus, the study did not consider addresses mistyped or absent. Each of the addresses for every publication was split into two parts: Institution and country. A publication written by authors from the same country was counted as single addressed for analyzing countries' performance; and similarly, by authors from the same institution was counted as single addressed for analyzing institutions' performance. A publication was considered collaborative providing at least two authors from different countries contributed the paper. Bilateral relations were identified for each publication and outlined in a network map.

The h-index is a norm that shows the significance of author. WoS provides number of citations for individual publications. h-indices of countries, research centers and journals were calculated based on 'times cited' information by the time that publication records downloaded. IFs of the journals were gathered from journals' own websites based on 2015 JCR.

3. Results and discussion

3.1. General information about publications

Fig. 1 shows annual number of publications and authors on the left side, and authors per publication on the right side. Number of articles per annual increased drastically throughout the period inspected from 6,607 to 20,638 that is roughly three times more than in 1997. Number of authors increased faster than the number of publications; accordingly, number of authors per publication rose from 2.3 to 3.6. Average page number per article did not show a significant change; so roughly, each publication consists of 10 (±1) pages.

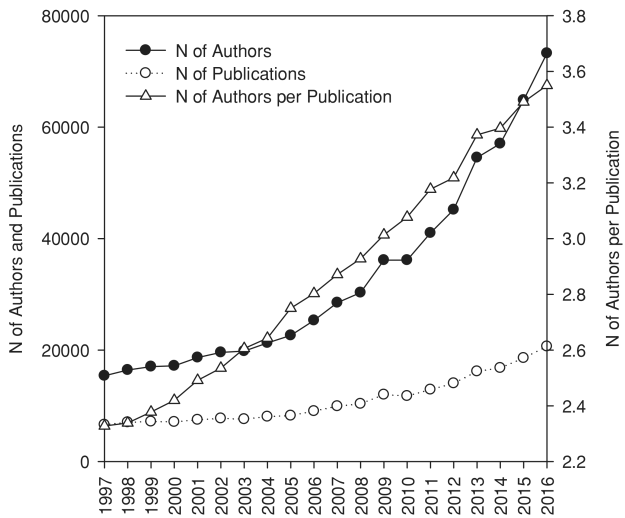

Fig. 1. Evolution of number of publications, number of authors, and number of authors per publication

English is the dominating language of publications with a high percentage of 98.0%, as expected. Other languages encountered are Japanese, German, French, Slovene, Croatian, Turkish, Chinese, Slovene English, Slovak, Spanish, English Estonian, Rumanian, Czech, Welsh, and Georgian.

Table 1 shows the distribution of publications by WoS Category. An article may concern more than one research areas. Articles in the field of mechanical engineering published during 1997–2016 were related to 35 WoS Categories indicating the broadness of the field. As expected, mechanics and thermodynamics, highly significant areas for mechanical engineering, were dominating during the period. Nearly thirty percent (29.6%) of articles were related to mechanical issues, whereas, thermodynamics make up 24.0% of all. Optics and Sport sciences showed up after 2007 and were less than a percentage of 1% of all publications.

Table 1.
Distribution of articles by WoS Category in mechanical engineering

WoS Category	Publications	
	#	%
Mechanics	64,897	29.6
Thermodynamics	52,705	24.0
Energy & Fuels	18,764	8.56
Materials Science, Multidisciplinary	16,917	7.72
Engineering, Chemical	16,302	7.44
Acoustics	15,845	7.23
Engineering, Manufacturing	14,664	6.69
Engineering, Civil	11,362	5.18
Engineering, Multidisciplinary	7,555	3.45
Transportation Science & Technology	6,592	3.01
Materials Science, Characterization & Testing	5,138	2.34
Engineering, Electrical & Electronic	4,802	2.19
Environmental Sciences	4,017	1.83
Meteorology & Atmospheric Sciences	4,017	1.83
Water Resources	3,702	1.69
Automation & Control Systems	3,665	1.67
Construction & Building Technology	2,638	1.20
Physics, Fluids & Plasmas	2,437	1.11
Engineering, Ocean	2,435	1.11
Engineering, Biomedical	2,038	0.930
Instruments & Instrumentation	1,735	0.792
Engineering, Aerospace	1,627	0.742
Computer Science, Artificial Intelligence	1,569	0.716
Physics, Applied	1,531	0.698
Statistics & Probability	738	0.337
Robotics	552	0.252
Computer Science, Interdisciplinary Applications	545	0.249
Materials Science, Composites	356	0.162
Nanoscience & Nanotechnology	353	0.161
Materials Science, Coatings & Films	307	0.140
Optics	222	0.101
Sport Sciences	219	0.100
Green & Sustainable Science & Technology	125	0.057
Computer Science, Hardware & Architecture	56	0.026
Computer Science, Information Systems	56	0.026

3.2. Evolution of research topics

Keywords were examined to highlight the most important research topics in the field. Of the records studied, 61,036 ones did not have keywords information. The remaining had 237,110 different keywords that classified into 187,497 groups by the algorithm as mentioned in Sec. 2. This algorithm brought out keywords' latent weight. For instance, the keyword 'computational fluid dynamics' and its variations reached an occurrence number of 2,262, whereas the exact match for the keyword was 1,078. Keywords 'finite element' and 'finite elements' were used in articles 877 and 618 times, respectively. The algorithm added up all variations of 'finite elements' and ranked it among top keywords.

Keywords used only once comprised 66.0% (123,720) of all keywords. The 5.58% (10,467) of the keywords appeared in more than 10 articles and only 0.446% (837) in more than 100. Table 2 lists top 20 author keywords and their variations at four-year intervals.

Table 2 indicates that 'heat transfer', 'finite element method/model (FEM)', 'friction', 'wear', 'modelling', 'simulation', and 'fatigue' were stand out over years and kept their importance with high publication rates. Although finite element method and finite element analysis (FEA) are somewhat different in meaning, they might be used as if they were synonyms. While finite element method should mention development of methods, finite element analysis should be preferred to signify application of the method for industrial purposes. It is convenient to insulate these keywords. Nevertheless, both of them were highly used keywords by authors. The keyword 'finite element' might also imply 'finite element method' or 'finite element analysis'. 'computational fluid dynamics (CFD)', and 'optimization' were other most frequently used author keywords that appeared in more than 1% of articles. All these words indicate that researchers seek inexpensive methods to predict behavior of matter.

Fig. 2 shows evolution of the most used keywords in the period 2013-2016. The vertical axis of the figure shows the occurrence number of keywords. These keywords were unusual in the period 1997-2000 and occurred less than 15 times in articles. There was an upward trend in research related to 'nanofluids', 'microchannel', 'phase change materials (PCM)', 'particle image velocimetry (PIV)', 'fluid/structure interaction (FSI)', 'faults diagnosis', 'structural health monitoring (SHM)', 'functionally graded materials (FGM)', 'nusselt number', 'flow boiling', 'wind turbines', 'multi objective optimization', 'lattice boltzmann method (LBM)', 'carbon nanotubes', and 'time delay'. 'nanofluids' came up both in top-ranked keywords list and promising keywords list. In other words, researches on nanofluids increased noticeably in recent years and already reached an important level. It can be inferred from the keywords mentioned above that scientists continue developing new materials to solve problems or enhance the performance of preexisting ones. For example, nanofluids may help heat transfer enhancement and CFD may help understanding behavior of nanofluidic systems. Similarly, engineers should wonder fatigue strength and wear characteristics of newly developed structural materials. A fault in an operating mechanical system may result in unwanted situations like occupational accidents, loss of time, and cost. Thus, engineers want to know the life of components of machines. Fault diagnosis and structural health monitoring could solve this problem. Another problem of operating systems that causes malfunction is vibration. Vibration related researches also include fatigue, wear, and finite element.

Table 2.

Most frequently used author keywords and their evolution over four-year intervals

Keywords	1997–2000		2001–2004		2005–2008		2009–2012		2013–2016		TP		
	#	R	#	R	#	R	#	R	#	R	#	R	%
Heat Transfer	435	1	760	1	710	1	1,125	1	1,515	1	4,545	1	2.07
Finite Element Modeling/Method	253	4	356	3	550	2	784	2	1,078	2	3,021	2	1.38
Friction	256	3	321	5	547	3	684	3	790	7	2,598	3	1.19
Wear	277	2	334	4	493	5	629	7	820	6	2,553	4	1.16
Modelling	208	5	380	2	533	4	594	8	552	10	2,267	5	1.03
Computational Fluids Dynamics (CFD)	94	23	137	19	337	11	673	4	1,021	3	2,262	6	1.03
Optimization	120	12	243	6	362	7	657	6	872	5	2,254	7	1.03
Finite Element Analysis (FEA)	125	10	200	10	342	9	662	5	741	8	2,070	8	0.944
Numerical Simulation	102	17	159	13	342	10	542	9	891	4	2,036	9	0.929
Simulation	140	8	236	8	404	6	479	10	496	13	1,755	10	0.801
Fatigue	176	6	239	7	279	13	399	12	435	18	1,528	11	0.697
Finite Elements	130	9	196	11	316	12	356	14	523	12	1,521	12	0.694
Porous Media	64	46	161	12	220	15	452	11	539	11	1,436	13	0.655
Natural Convection	99	19	149	17	262	14	391	13	465	15	1,366	14	0.623
Experiment	95	22	149	16	356	8	341	15	402	21	1,343	15	0.613
Vibration	97	20	157	14	210	18	306	18	480	14	1,250	16	0.570
Stability	107	15	153	15	217	16	304	19	426	20	1,207	17	0.551
Surface Roughness	100	18	136	20	212	17	318	17	437	17	1,203	18	0.549
Genetic Algorithm	61	48	109	31	208	19	298	21	431	19	1,107	19	0.505
Nanofluids	2	3,807	4	3,031	75	100	335	16	681	9	1,097	20	0.500

TP: Total number of publications keywords existed, R: Rank

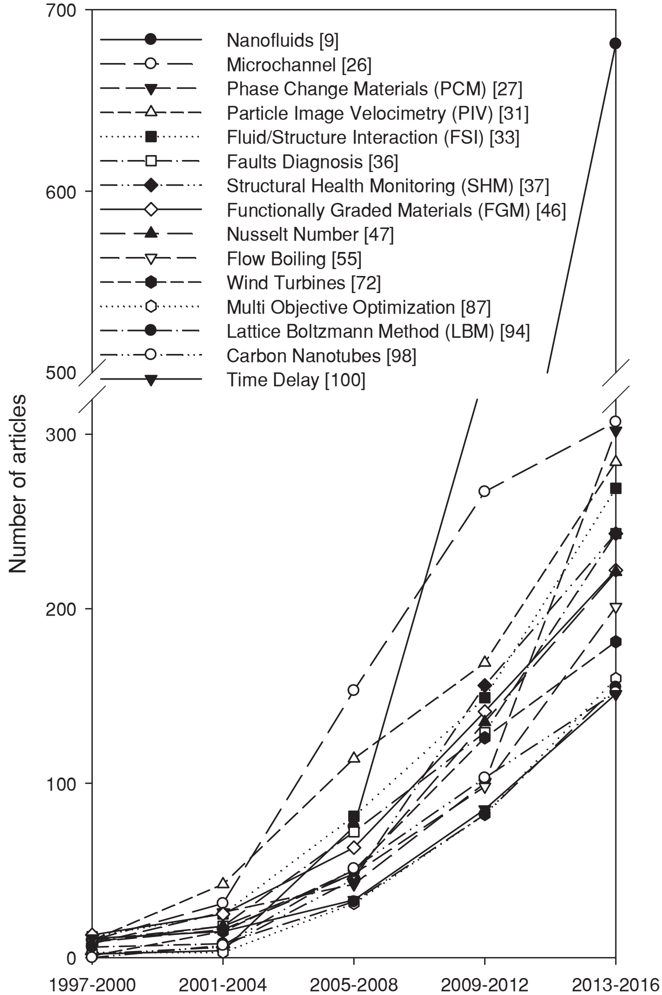

Fig. 2. Promising keywords selected thanks to rapid increase in rank during the period 1997–2016. Numbers in square brackets show rank of keyword in last period

Fig. 3 states promising keywords used more than 100 times since they first appeared after the year 2001. It is clear from the figure that ‘carbon nanotubes’, ‘homogeneous charge compression ignition (HCCI)’, ‘friction stir welding’, ‘biodiesel’, ‘vortex induced vibrations (VIV)’, ‘particle swarm optimization’, ‘support vector machines (SVM)’, ‘energy harvesting’, ‘sediment transfer’, ‘open channel flow’, ‘additive manufacturing’, ‘ionic liquids’, ‘micro fluid’, ‘empirical mode decomposition (EMD)’, ‘magnetic refrigeration (MR)’, ‘particle size distribution (PSD)’, ‘chaotic systems’, ‘damage (level) identification’, ‘micro combustion/combustor’, ‘ice slurry’, ‘ls dyna’, ‘magnetorheological damping’, and ‘surface texturing’ are emergent topics of the field.

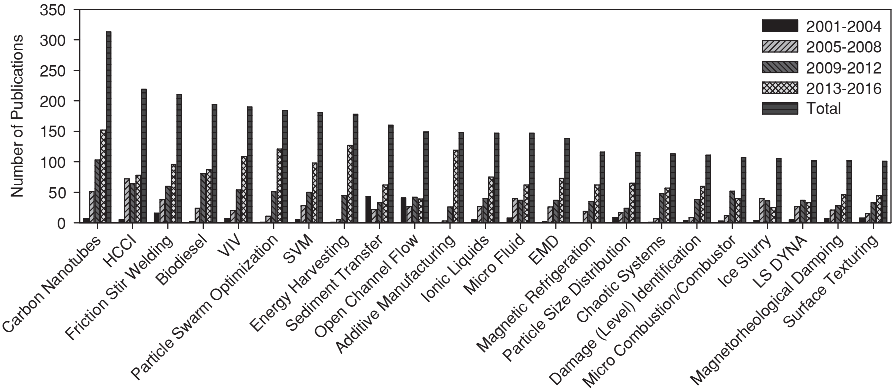

Fig. 3. Emergent keywords selected thanks to recent increase in rank

Nowadays, energy issues are popular both politically and industrially. Scientists from different disciplines look for new energy sources besides enhancing efficiency of the existing ones. Outputs of keywords analysis corroborated this by the keywords ‘wind turbines’, ‘homogeneous charge compression ignition (HCCI)’, ‘biodiesel’, ‘energy harvesting’, and ‘micro combustion/combustor’.

3.3. Productiveness of Countries

Table 3 gives information about productiveness of top 15 countries on the basis of the number of publications. The United States of America (USA) was the most productive country with a substantial contribution to articles of 46,765 that accounts for 21.3% of all articles. The top five most productive countries are the USA, China, South Korea, Japan, and England. The USA addressed articles were so respected with an h-index of 185 followed by of 115. The correlation between gross domestic product [15] and productiveness of countries draws attention such that the higher the gross domestic product, the higher the productivity. In addition, highly industrialized countries known as the G7 (the G8 countries except Russia) were dominating in the list.

Fig. 4 shows evolution of top 15 countries over years based on number of publications. The vertical axis shows the number articles in a logarithmic scale. China, India, and Iran in particular draw attention due to rapid increase in ranking of most productive countries as seen in the figure. China rose from a rank of 5 to 1 over last 20 years. India and Iran increased their rank during the period concerned from 11 and 43 to 4 and 5, respectively. Besides these countries, South Korea, Turkey, and Spain published more articles recently than in the first period considered. It is possible to say that developing countries classified by the International Monetary Fund (IMF) [16] have an upward trend in technology research.

Single country publications made up 79.7% of articles considered. Single publications of the USA constituted 15.6% of the articles. China made 13.6% of

Table 3.

Most productive countries

Country	TP	TP% (R)	SP% (R)	CP% (R)	RP (R)	h (R)	h_{10}	h_{100}	TP_{10}	TP_{100}
USA	46,765	21.3 (1)	15.6 (1)	5.72 (1)	41.2 (2)	185 (1)	7	41	4	21
China	38,444	17.5 (2)	13.6 (2)	3.99 (2)	61.5 (1)	115 (2)		13	5	23
South Korea	14,670	6.69 (3)	5.27 (3)	1.43 (7)	62.3 (4)	84 (9)		3		8
Japan	13,628	6.22 (4)	4.76 (4)	1.46 (6)	37.2 (8)	89 (7)		4		6
England	13,507	6.16 (5)	3.69 (7)	2.47 (3)	42.4 (3)	105 (3)	1	8		10
India	10,065	4.59 (6)	3.85 (6)	0.741 (11)	47.1 (12)	80 (10)	1	1	1	3
France	9,912	4.52 (7)	2.81 (9)	1.71 (4)	39.0 (5)	98 (5)		4		2
Canada	8,526	3.89 (8)	2.50 (10)	1.39 (8)	45.0 (6)	92 (6)		6		4
Germany	8,517	3.89 (9)	2.31 (13)	1.57 (5)	36.1 (7)	103 (4)		1		1
Taiwan	7,435	3.39 (10)	3.00 (8)	0.391 (20)	60.0 (14)	73 (13)		3		3
Italy	7,221	3.29 (11)	2.33 (12)	0.964 (10)	50.2 (9)	88 (8)		3		2
Iran	6,652	3.03 (12)	2.39 (11)	0.648 (12)	54.0 (11)	65 (17)				5
Australia	4,918	2.24 (13)	1.22 (15)	1.03 (9)	43.3 (10)	75 (12)		1		2
Turkey	4,122	1.88 (14)	1.49 (14)	0.389 (21)	51.7 (17)	66 (16)				
Spain	4,006	1.83 (15)	1.20 (16)	0.626 (13)	53.4 (13)	68 (14)				1

TP: total number of articles; TP%: percentage of articles; SP%: percentage of independent articles in TP; CP%: percentage of internationally collaborative articles in TP; RP%: percentage of articles with corresponding author in CP; h: h-index; R: Rank; h_{10}: number of institutions in top 10 by h-index; h_{100}: number of institutions in top 100 by h-index; TP_{10}: number of institutions in top 10 by number of publications; TP_{100}: number of institutions in top 100 by number of publications

articles on its own and contributed 3.99% of collaborative publications (Table 3). Fig. 5 shows contributions of countries to knowledge in mechanical engineering based on single publications. The USA published 19.6% of all single country publications. The graph also indicates that 82.6% of publications come from 15 countries.

About twenty percent of articles investigated have contributions of at least two countries. Fig. 6 shows the network of collaborative countries. In the figure, the bigger the circle is, the higher the collaborative publications. Similarly, line thickness represents intensity of collaboration between countries. The smallest circle means that the country represented by this circle has 50 collaborative publications at least, and the thinnest line indicates that countries connected with this line have 50 collaborations at least. The most collaborative country is the USA that contributed 28.2% of all collaborative articles. As shown in the network graph, other cooperative countries are China, England, France, Germany, Japan, South Korea, and Canada. Researchers from the USA wrote 2,919 papers with their colleague from China that corresponds 6.57% of all collaborative publications. The partnership of the USA and South Korea were responsible for 3.45% of co-worked papers, while China and England collaboration was 2.82%.

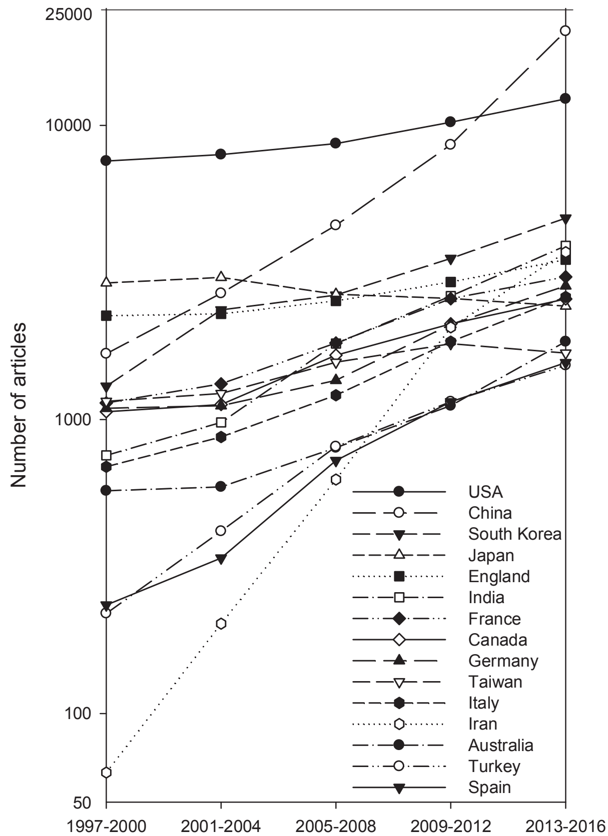

Fig. 4. Evolution of top 15 countries over years based on number of articles

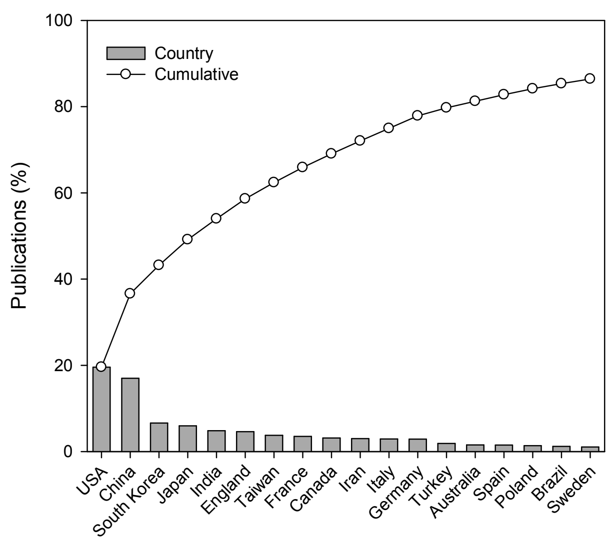

Fig. 5. Distribution of publications to countries

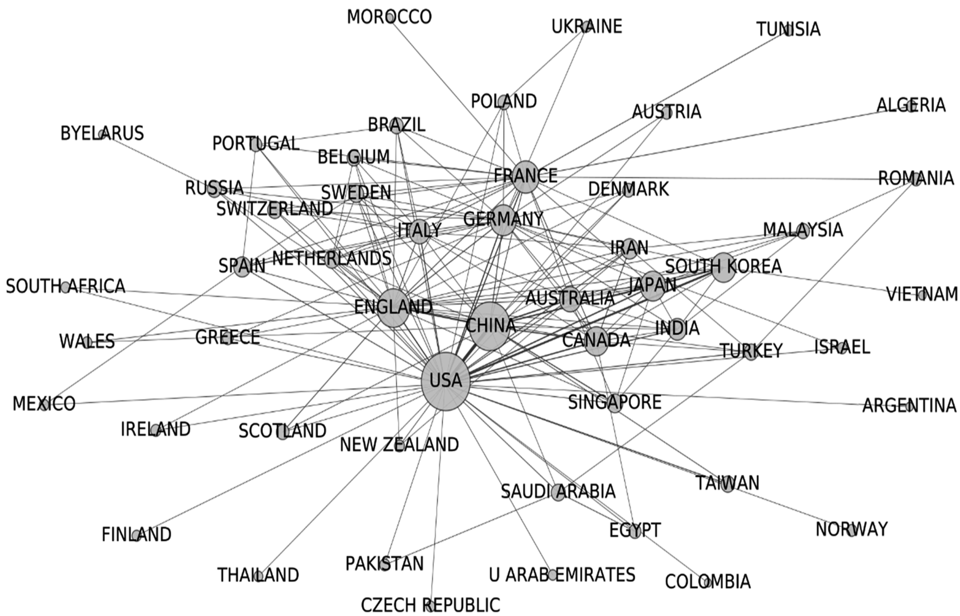

Fig. 6. International collaborations network

3.4. Productiveness of Research Centers

During the period 1997-2016, 41,677 different research centers contributed to the knowledge. Table 4 lists most productive 20 institutions. Each institution in the list contributed to more than 0.500% of the articles. Indian Institutes of Technology published 1.00% of articles on its own effort and contributed 0.663% of collaborative publications with an h-index of 73. University of Illinois, Purdue University, University of Michigan, and Georgia Institute of Technology, stand out as high number of publications and have h-indices of 74, 72, 67, and 63, respectively.

Besides universities in the list, University of Colorado, Massachusetts Institute of Technology, Stanford University, and North Carolina State University are other eminent universities with respect to their number of citations despite having relatively lower number of publications than of universities in Table 4. Number of research centers in top lists is another indicator that shows competencies of countries. According to Table 3, seventy-three of most productive institutions in top 100 came from six countries. When sorting research centers by h-index, the seven of the top 10 ranked ones located in the USA. Other three research centers of the list were in England, Singapore, and India. The USA was the leading country of top 100 h-index list of research centers with a number of 41 institutions and followed by China (13), England (8), and Canada (6). According to the number of publications, five most productive institutions in top 10 and 23 in top 100 come from

Table 4.

Most productive 20 institutions

Institution; Country	TP	TP% (R)	SP% (R)	CP% (R)	RP% (R)	h (R)	C_p
Indian Inst Technol; India	3,652	1.67 (1)	1.00 (1)	0.663 (1)	43.6 (3)	73 (2)	12.8
Shanghai Jiao Tong Univ; China	2,836	1.29 (2)	0.686 (2)	0.608 (3)	62.9 (1)	58 (12)	9.13
Chinese Acad Sci; China	2,317	1.06 (3)	0.400 (4)	0.657 (2)	52.1 (2)	52 (19)	9.04
Xi An Jiao Tong Univ; China	1,981	0.904 (4)	0.473 (3)	0.431 (8)	65.7 (4)	43 (51)	6.92
Tsinghua Univ; China	1,862	0.849 (5)	0.353 (6)	0.496 (4)	51.4 (5)	41 (65)	7.03
Univ Illinois; USA	1,750	0.798 (6)	0.319 (8)	0.479 (5)	42.4 (9)	74 (1)	18.4
Purdue Univ; USA	1,644	0.750 (7)	0.349 (7)	0.401 (9)	47.5 (14)	72 (3)	18.6
Univ Michigan; USA	1,634	0.745 (8)	0.310 (10)	0.436 (7)	41.6 (16)	67 (5)	16.2
Harbin Inst Technol; China	1,485	0.677 (9)	0.312 (9)	0.366 (10)	56.1 (8)	39 (80)	7.19
Georgia Inst Technol; USA	1,457	0.665 (10)	0.303 (11)	0.361 (11)	46.1 (17)	63 (6)	15.2
Seoul Natl Univ; South Korea	1,417	0.646 (11)	0.205 (26)	0.441 (6)	54.0 (6)	54 (14)	11.1
Natl Cheng Kung Univ; Taiwan	1,401	0.639 (12)	0.379 (5)	0.260 (31)	50.0 (27)	46 (34)	10.2
Dalian Univ Technol; China	1,381	0.630 (13)	0.281 (13)	0.349 (12)	56.9 (10)	32 (157)	5.55
Korea Adv Inst Sci & Technol; South Korea	1,358	0.620 (14)	0.284 (12)	0.335 (13)	56.3 (15)	46 (33)	10.8
Zhejiang Univ; China	1,314	0.599 (15)	0.266 (15)	0.333 (14)	59.2 (11)	40 (73)	7.3
Nanyang Technol Univ; Singapore	1,295	0.591 (16)	0.271 (14)	0.320 (16)	46.4 (22)	57 (13)	15.5
Texas A&M Univ; USA	1,209	0.552 (17)	0.224 (22)	0.328 (15)	42.4 (25)	54 (15)	13.9
Hanyang Univ; South Korea	1,190	0.543 (18)	0.246 (17)	0.297 (21)	64.7 (13)	37 (95)	7.45
Natl Univ Singapore; Singapore	1,165	0.531 (19)	0.245 (18)	0.287 (23)	39.0 (34)	59 (9)	17.5
Pusan Natl Univ; South Korea	1,163	0.531 (20)	0.218 (24)	0.313 (17)	66.2 (7)	32 (156)	5.74

TP: total number of articles; TP%: percentage of articles; SP%: percentage of independent articles in TP; CP%: percentage of internationally collaborative articles in TP; RP%: percentage of articles with corresponding author in CP; h: h-index; R: Rank; C_p: number of citations per article

China. Some other countries in top 100 were, with the number of research centers in brackets, USA (21), England (10), and South Korea (8). Considering the number of publications and number of research institutions, as stated in World Bank report [17], intensity of research activities is directly proportional to economic development of the countries.

Fig. 7 shows change in the ranking of 10 promising institutions by number of publications in the period 2013-2016. The vertical axis of the figure shows number of publications contributed by institution. It is worth to say that outnumbering of Chinese institutions draws attention. Islamic Azad University from Iran and Beihang University from China are outstanding research centers among emergent ones that had no publications in the field before 2000.

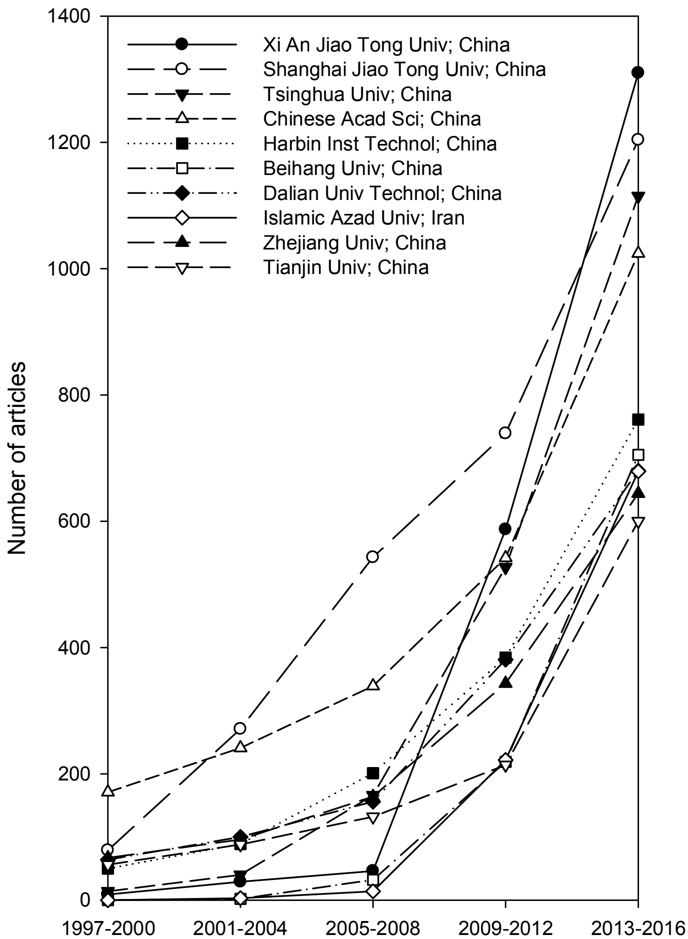

Fig. 7. Evolution of promising institutions

3.5. Journals

Authors of the field published their articles in 168 journals, and 54 of these journals (32.1%) published 70.4% of articles. Table 5 shows most stimulating journals ranked in top 20. Correlation between journals' titles and mostly used keywords such as 'heat transfer', 'vibration', and 'wear' takes attention. International Journal of Heat and Mass Transfer was the leading journal both in number of publications and citations. Consequently, it has an h-index of 134 and an IF of 2.857. Journal of Sound and Vibration and Applied Thermal Engineering were other journals published more than 5,000 articles. Combustion and Flame, Journal of Sound and Vibration, International Journal of Plasticity, and Wear were in top five according to h-indices of 109, 105, 92, and 88, respectively.

Table 5.

Most stimulating journals.

Journals	TP	TP% (R)	h (R)	C_p	IF
Int. J. Heat Mass Transf.	12,010	5.48 (1)	134 (1)	18.5	2.857
J. Sound Vibr.	9,631	4.39 (2)	105 (3)	16.0	2.107
Appl. Therm. Eng.	7,798	3.56 (3)	87 (6)	12.2	3.043
Wear	4,594	2.10 (4)	88 (5)	18.4	2.323
Nonlinear Dyn.	4,559	2.08 (5)	69 (16)	11.0	3.000
J. Mech. Sci. Technol.	4,414	2.01 (6)	24 (74)	2.98	0.761
Combust. Flame	4,249	1.94 (7)	109 (2)	24.2	4.168
Prof. Eng.	3,467	1.58 (8)	6 (147)	0.130	*
Proc. Inst. Mech. Eng. Part C – J. Eng. Mech. Eng. Sci.	3,328	1.52 (9)	34 (50)	4.26	0.978
Exp. Fluids	3,295	1.50 (10)	69 (17)	13.8	1.570
J. Heat Transf.-Trans. Asme	3,172	1.45 (11)	76 (11)	13.7	1.723
Tribol. Int.	3,150	1.44 (12)	58 (27)	11.6	2.259
Int. J. Therm. Sci.	2,988	1.36 (13)	68 (19)	14.1	2.769
Mech. Syst. Signal Proc.	2,967	1.35 (14)	86 (7)	17.7	2.771
Int. J. Fatigue	2,942	1.34 (15)	67 (20)	14.8	2.162
Int. J. Mech. Sci.	2,929	1.34 (16)	67 (21)	13.7	2.481
Proc. Inst. Mech. Eng. Part B – J. Eng. Manuf.	2,778	1.27 (17)	33 (53)	5.39	0.978
Struct. Eng. Mech.	2,711	1.24 (18)	29 (63)	3.86	1.021
J. Fluids Eng. – Trans. Asme	2,683	1.22 (19)	55 (29)	8.63	1.283
Dry. Technol.	2,666	1.22 (20)	56 (28)	12.1	1.854

*This journal does not have an IF in 2015. In addition, articles published in this journal have not detailed information.

Fig. 8 states top 10 journals by the number of publications in the period 2013–2016. The figure presents the evolution of journals over years by change in number of articles published shown on vertical axis. International Journal of Heat and Mass Transfer stands out throughout the period in keeping with the most used keyword ‘heat transfer’. Applied Thermal Engineering and Tribology International increased rapidly in rank. Advances in Mechanical Engineering and Journal of Vibroengineering were ascending journals of the field and indexed in WoS databases after the year 2007 and 2009, respectively.

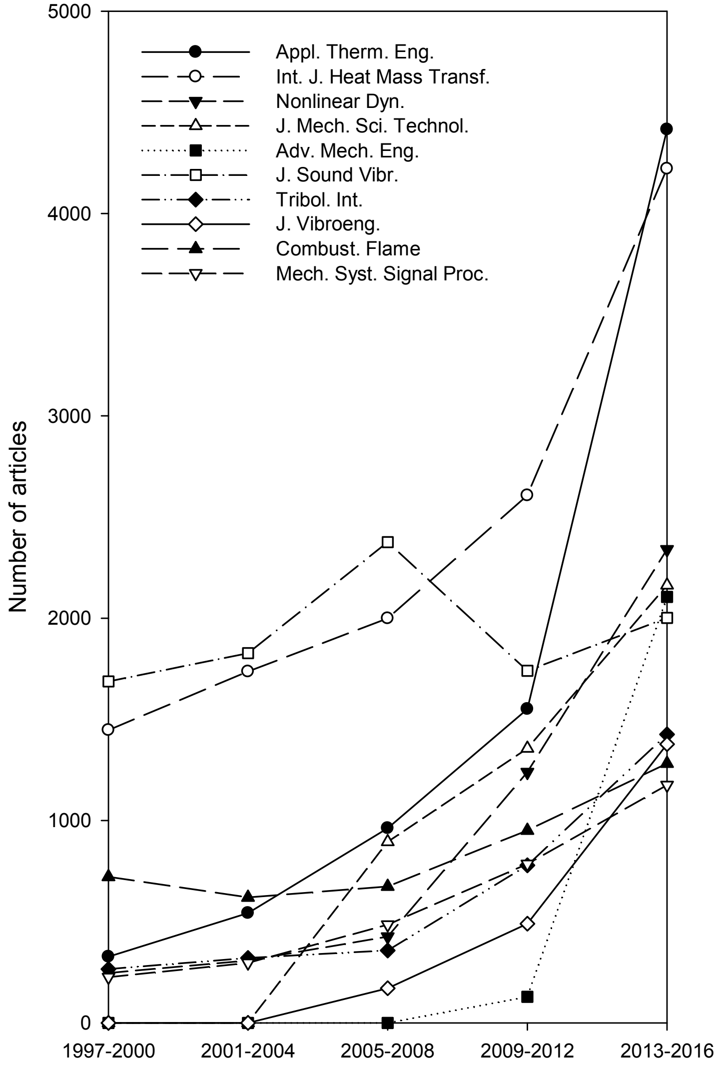

Fig. 8. Evolution of outstanding journals

4. Conclusions

The present paper gives results to spot research activities in the field mechanical engineering based on data from Web of Science Core collections, including 219,191 articles published throughout the period 1997–2016. Main outcomes to be drawn are as follows:

- Articles under consideration were related to thirty-five WoS Categories while mechanics and thermodynamics were dominating. The number of publications in the field Mechanical Engineering has grown over years and tripled throughout the years concerned. Ninety-eight percent of publications were in English.

- The number of keywords used only once comprised 66.0% of all keywords and only 5.58% of keywords appear in more than 10 articles and 0.446% in more than 100. 'heat transfer', 'finite element method/model', 'friction', 'wear', 'modelling', 'simulation', and 'fatigue' were mostly used keywords of the field over years. There is an upward trend in research related to 'nanofluids', 'microchannel', 'phase change materials', 'particle image velocimetry', and 'fluid/structure interaction'. Researches about 'carbon nanotubes', 'homogeneous charge compression ignition', 'friction stir welding', and 'biodiesel' are emergent topics. New structural materials and fluids stimulate researches that aim to understand behavior of materials with regard to heat transfer, wear, fatigue, etc. In addition, computational methods constituted a considerable part of researches.
- Eighty-two percent of publications came from fifteen countries. The USA was the dominating country of the field and contributed 21.3% of all publications. Other outstanding countries were China, South Korea, Japan, and England. China, Brazil, and Iran in particular among these countries draw attention due to rapid increase in ranking of most productive countries by the number of publications. Seventy-three percent of most productive 100 institutions come from six countries. Nine of the top 10 ranked ones are located in China (5) and the USA (4). It is worth to say that there is a positive relation between the technological development and research activities of countries.
- Nearly eighty percent (174,762) of the articles were published by a single country, the remaining were the result of a collaboration. The most collaborative country, the USA, contributed 28.2% of collaborative publications. Other most cooperative countries were China and England.
- Research centers published nearly half of the publications on their own. Indian Institutes of Technology, University of Illinois, Purdue University, University of Michigan, and Georgia Institute of Technology stand out as high number of publications and h-indices.
- Authors of the field published their articles in 168 journals. Seventy percent of articles came out in 54 journals. International Journal of Heat and Mass Transfer was the leading journal both in number of publications (12,010) and h-index (134).

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