BRAZILIAN SCIENTIFIC PRODUCTION IN THE MECHANICAL ENGINEERING AREA

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Abstract. *The article aims to provide indicators of the Brazilian scientific production in the mechanical engineering area in the period 2003-2008 showing the evolution of the number of articles, the quantity of papers written in collaboration with other countries and institutions, the interaction with other subject areas, the main journals that have published Brazilian articles and the papers with more number of citations. The research was based on data from articles indexed in the Web of Science accessed through the CAPES Journal Portal. Some of the results showed that the number of Brazilian scientific articles in mechanical engineering has varied over the years; the scientific collaboration with other countries – based on co-authorship – increased with 24% of the total of articles published involving partnership with international institutions; and the main interaction with other subject areas happens with mechanics and thermodynamics. This work intends to contribute to a better understanding of the organization and dynamics of this field of knowledge in Brazil.*

Keywords*: ST&I indicators, academic production, engineering education, mechanical engineering*

1. INTRODUCTION

The Ministry of Science and Technology of Brazil has organized and presented national ST&I (Science, Technology and Innovation) indicators which include scientific production, patents, human resources and other. These indicators are used to provide subsidies for the establishment of policies for ST&I and to define priorities, allocation of investments, program formulation and processes of evaluation.

The scientific production indicator of a country is measured by the amount of articles published in international journals indexed in ISI/Web of Science database which is widely recognized as one of the most important, if not the most important, base of information on scientific production of the world (MCT, 2009a). In this indicator, Brazil is occupying the 15th position of international ranking representing almost 2% of world production. Each knowledge area, however, presents specific performance and characteristics. In 2006, for example, Brazilian Agricultural Sciences represented 4,28% of the total of scientific production of the world in this knowledge area; Science of Animals/Plants represented 3,42%; Physical represented 2,12%; and Pharmacology represented 2,50%. Other areas didn't have the same performance as Education that represented 0,40 and Law 0,11. Brazilian engineering corresponded to 1,36% of the international production within the Engineering (MCT, 2009b).

But, what is the contribution of Brazilian mechanical engineering? What are the characteristics of this subarea of the Engineering in Brazil? The indicators presented by MCT are limited to counting the number of articles, however, it is possible to obtain various other information from articles published in order to better know a specific field of knowledge.

The article aims to provide indicators of the Brazilian scientific production in the mechanical engineering area in the period 2003-2008 showing the evolution of the number of articles, the quantity of papers written in collaboration with other countries and institutions, the interaction with other subject areas, the main journals that has published Brazilian articles and the papers with more number of citations. The research was based on data from articles indexed in the Web of Science accessed through the CAPES Journal Portal. This work is organized in the following sections: context; method; results; and conclusion.

2. CONTEXT

In the last decades, the interest in measuring the development of scientific and technological activities of the countries has presented considerable growth. The increasing of the importance of the knowledge and innovation for the competitiveness has forced the governments around the world to invest in the creation and organization of statistical databases to provide subsidies for the establishment of policies for ST&I.

To be possible the international comparison of indicators, it is necessary the definition of common methodological standards to be adopted by different countries. With respect to ST&I indicators, the most of the countries – including Brazil – has adopted the recommendations of the manuals of the Organization for Economic Co-operation and Development – OECD. They are: Frascati Manual, specific to R&D activities; Oslo Manual related to innovation;

Technological Balance of Payments – TBP Manual; Canberra Manual for human resources; and the Patents Manual (MCT, 2009c).

The international literature defines three kinds of indicators related to Science, Technology and Innovation (ST&I): 1) indicators of input consisting in spending and human resources in R&D (Research and Development); 2) indicators of results (output) that intend to measure the scientific and technological production through of publications and patents including the technology transfer between countries (technological balance of payments); and 3) indicators of impact, still incomplete, with the aim of to measure how a specific scientific or technological result affects the various dimensions of the society (Mugnaini et al., 2005; Ferreira e Negreiros, 2005; MCT, 2009d).

Scientific publications are therefore an indicator of result that reflects the scientific productivity in a special field of knowledge. The most usual way of measuring this indicator is through of scientific articles published in journals indexed in the ISI/Web of Science as mentioned in the introduction of this work.

According to Tijssen (1992 *apud* Verbeek et al, 2002) scientific publications can provide quantifiable elements related to three main aspects of scientific activity: 1) the product – represented by the number of the research publications – reflects the 'size' of scientific activities; 2) the process – represented by the transfer of knowledge – happens with the disclosed of the original findings of the researches and with the citations that contribute to dissemination of the knowledge into the scientific community; and 3) the structure – represented by social and cognitive networks – can be studied through of the scientific collaboration based on the co-authorship of the articles published.

Although there are other manners of interaction between researchers, the co-authorship consists in one of the main indicators of the social organization of a scientific community (Crane, 1972 *apud* Silva et al., 2007). Furthermore it is easy to measure (Subramanyam, 1983; Cronin et al, 2003) and the documents can be accessed by Internet. These factors contribute to the co-authorship is widely used in bibliometric studies.

3. METHOD

The research was based on bibliometric approach of scientific production published in international journals indexed in ISI/Web of Science database in the period 2003-2008 related to Brazilian engineering mechanical area. The bibliometric approach offers advantages as economical, accessible and easy to implement. *This approach also permits rapid inter-temporal comparisons and is capable of examining a higher representation of the universe under investigation and adapt well to international comparisons* (ABRAMO et al., 2009).

In this research was used the following parameters of search: Address=("Brasil" or "Brazil" or "Bresil") AND Document Type=(Article) refined by Subject Areas=(ENGINEERING, MECHANICAL); Timespan=2003-2008; and Databases=SCI-EXPANDED. The results recovered were also refined by countries, subject areas, institutions and source titles. The data from the articles were exported to a table into Excel to be analyzed by quantity and kind of authors and institutions. The Citation Report, that reflects citations to source items indexed within Web of Science database, was used too.

A complementary search was made using the parameter of search Timespan=1998-2003 to observe data related to the total of Brazilian academic production and the total of Mechanical Engineering area to identify the growth of the number of articles published. Also was realized a search considering other sub areas of engineering, in the period 2003-2008, to compare the performance of these sub areas with the mechanical engineering.

4. RESULTS

The search retrieved 97.828 Brazilian articles in the period 2003-2008 being 611 documents in the mechanical engineering area. In the period 1998-2003 were retrieved 56.621 documents being 303 in the mechanical engineering area. These results indicate a rate of growth of 1,73 related to the total of Brazilian production and of 2,02 related to mechanical engineering. Therefore the rate of growth of mechanical engineering was higher than the Brazilian involving all areas of knowledge. The rate of growth the mechanical engineering also was higher than the rate of other sub areas of engineering as chemical and electrical and electronic. Only biomedical engineering presented a rate of growth higher than mechanical engineering. These results are illustrated in Tab. 1. The accumulated distribution of the articles published in the period 2003-2008 is showed in Fig.1.

Table 1. Brazilian scientific production in the periods 1998-2003 and 2003-2008

Academic production of scientific articles	**1998-2003**	**2003-2008**	**Rate of Growth**
Total of Brazil	56.621	97.828	1,73
Total of Mechanical engineering area	303	611	2,02
Total of Chemical engineering area	921	1.697	1,84
Total of Electrical & Electronical engineering area	1.098	1.526	1,39
Total of Biomedical engineering	239	496	2,08

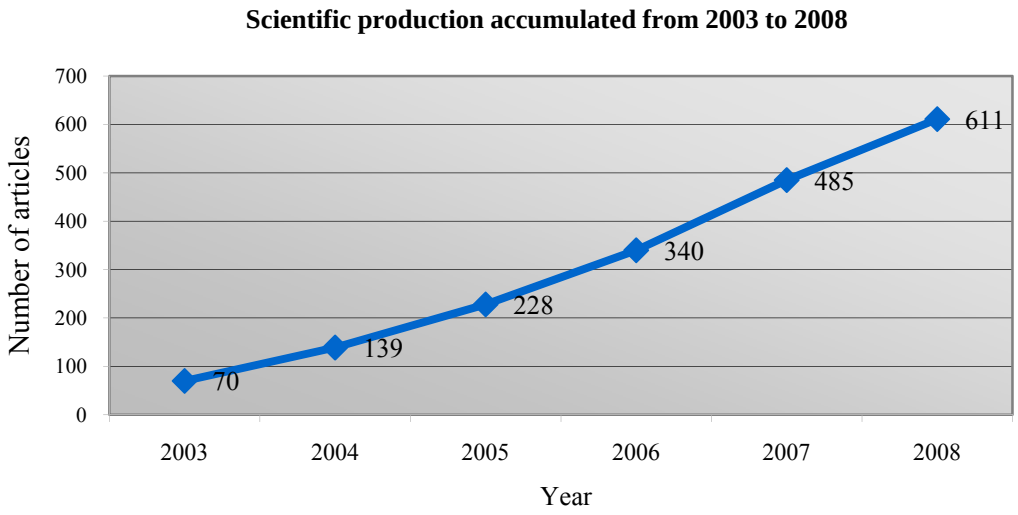

Figure 1. Brazilian scientific production accumulated from 2003 to 2008

The evolution of the number of Brazilian articles in mechanical engineering, however, varies over the years. The recent indexing of Journal of the Brazilian Society of Mechanical Sciences and Engineering and Latin American Journal of Solids and Structures in Web of Science database greatly contributed to the increasing of number of Brazilian articles in mechanical engineering area in the last two years, mainly in 2008, accounting for a total of 83 articles. The variation in the number of articles over the years also happens in some other countries as shown in Figure 2.

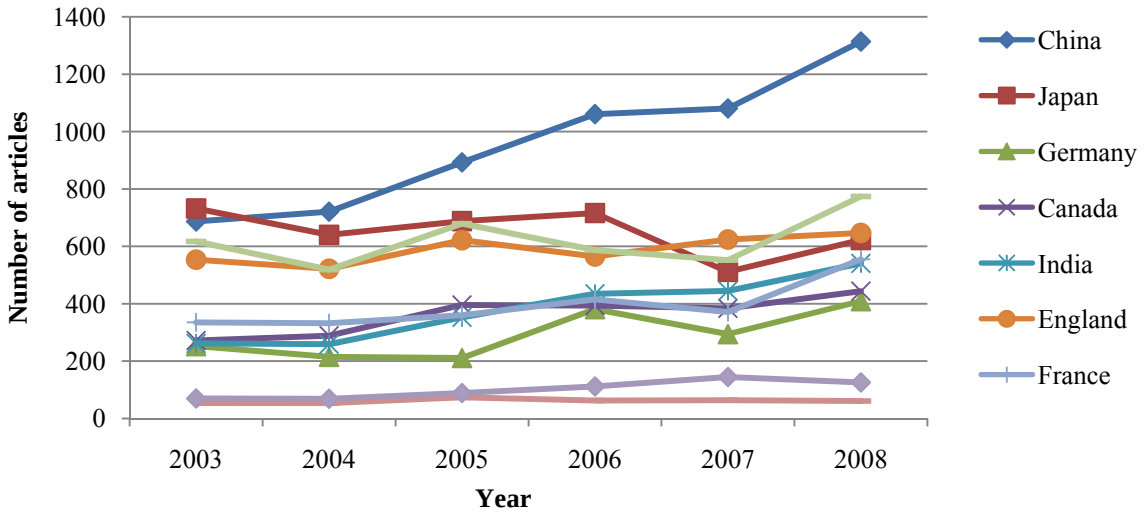

Figure 2. Evolution of number of articles in mechanical engineering area from selected countries

The international scientific collaboration – considering the co-authorship relation of the articles published – has increased. While in the period 1998-2003 there was international collaboration with 19 countries, in the period 2003-2008 this collaboration expanded to 37 different countries. The intensity of this collaboration increased too. In the period 1998-2003 only five countries presented at least five or more articles written in partnership with Brazil: USA (36 articles); England (25 articles); France (15 articles); Germany (5 articles); and Portugal (5 articles). In the period 2003-2008 this number increased to eleven countries with greater number of articles written in collaboration as illustrated in Fig. 3.

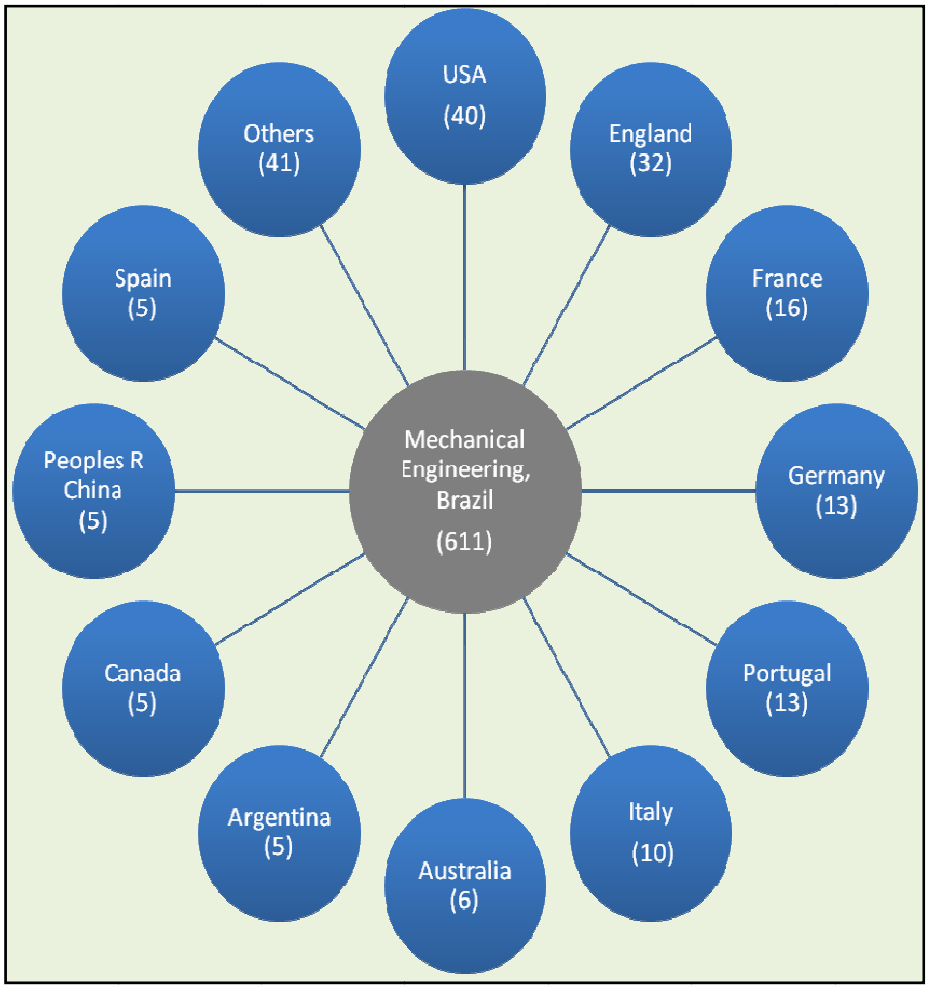

Figure 3. Co-authorship of scientific articles between Brazil and other countries

Considering the period 2003-2008, the Brazilian institutions with greatest number of articles published in mechanical engineering area were USP, UNICAM and UFRJ with 135, 67 and 60 articles respectively. Figure 4 shows the institutions that presented at least seven articles published. Considering the nineteen national institutions included in Fig. 4, only two institutions – UnB and UFC – aren't located in the Southeast and South regions of the country showing an intense concentration of the scientific production in the mechanical engineering area in these regions. It's possible to observe that two foreign universities – Duke University (USA) and South Bank University (England) – are related in Fig. 4 indicating co-authorship with Brazilian institutions.

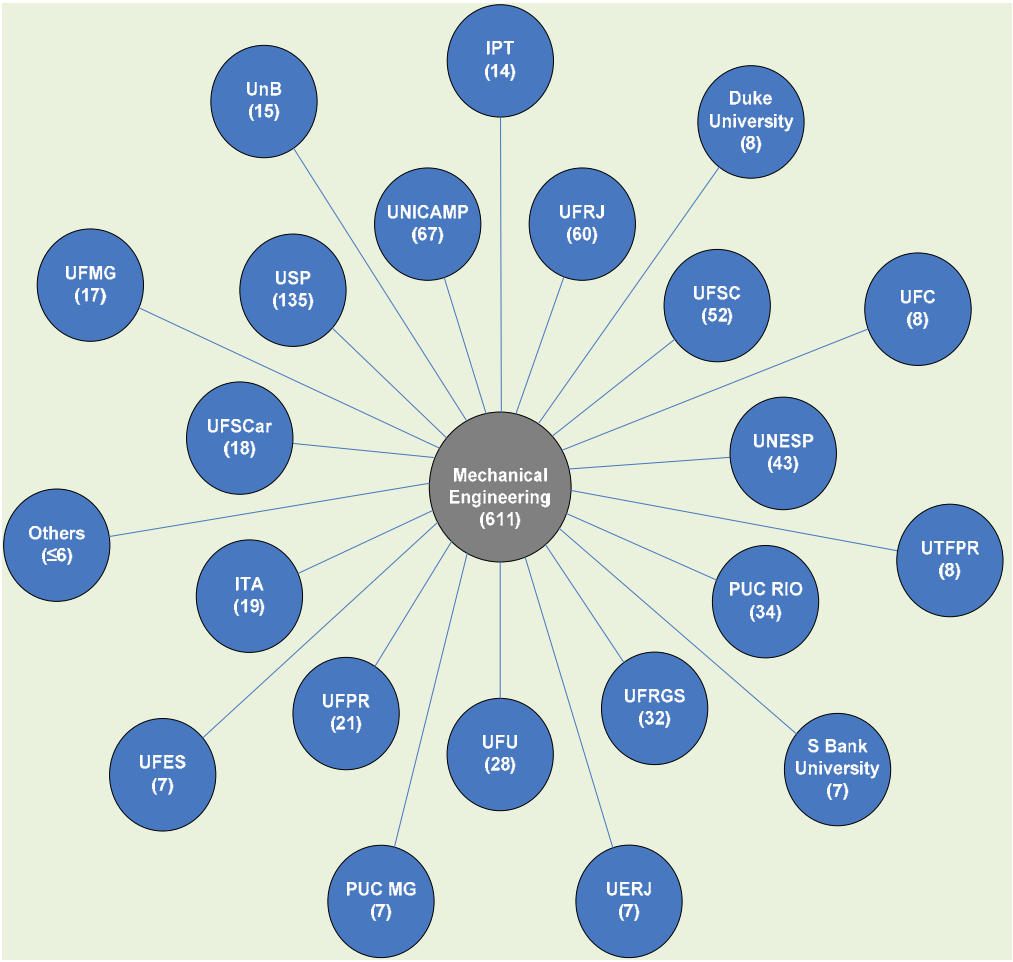

Figure 4. Brazilian institutions with greatest number of scientific articles in mechanical engineering area

Another aspect observed related to scientific collaboration was the quantity of authors and institutions in each article published in the mechanical engineering area. The research showed that more than 66% of the articles presented collaboration between two or three authors. Only 5% of them were written without partnership. Considering the collaboration between institutions, the results are quite different with 44,52% of the articles produced by a single institution. The number of articles written by two institutions also is significant corresponding to 40,43% of the total. More than half of articles therefore involved inter-institutional partnership as illustrated in Tab.2.

Table 2. Number of authors and institutions of the articles published in the mechanical engineering area

Number of author(s) and institution(s) per article	**Authors**		**Institutions**	
	Frequency	**%**	**Frequency**	**%**
1	31	5,07	272	44,52
2	201	32,90	247	40,43
3	206	33,71	70	11,45
4	103	16,86	17	2,78
≥ 5	70	11,46	3	0,49
Total	**611**	**100,00**	**609***	**99,67***

(*) two articles showed no relationship to Institutions.

Based on data from Tab.2, it's possible to observe that Brazilian production in mechanical engineering area presents a average of approximately 3 authors per article (considering the articles with more than five authors the average is 3,02). In reference to institutions, the average is around 1,7 institution per article.

The research also identified the relations of partnership of the articles published. Figure 5 shows that 274 articles (44,9% of the total) were written without inter-institutional collaboration; 147 articles (24%) were written in collaboration inter-institutional involving different universities and/or research institutions located in Brazil; 147

articles (24%) were written with international collaboration; and 37 articles (6%) in collaboration with Brazilian firms. The two firms that published articles in collaboration with international universities were Petrobras and Embraer.

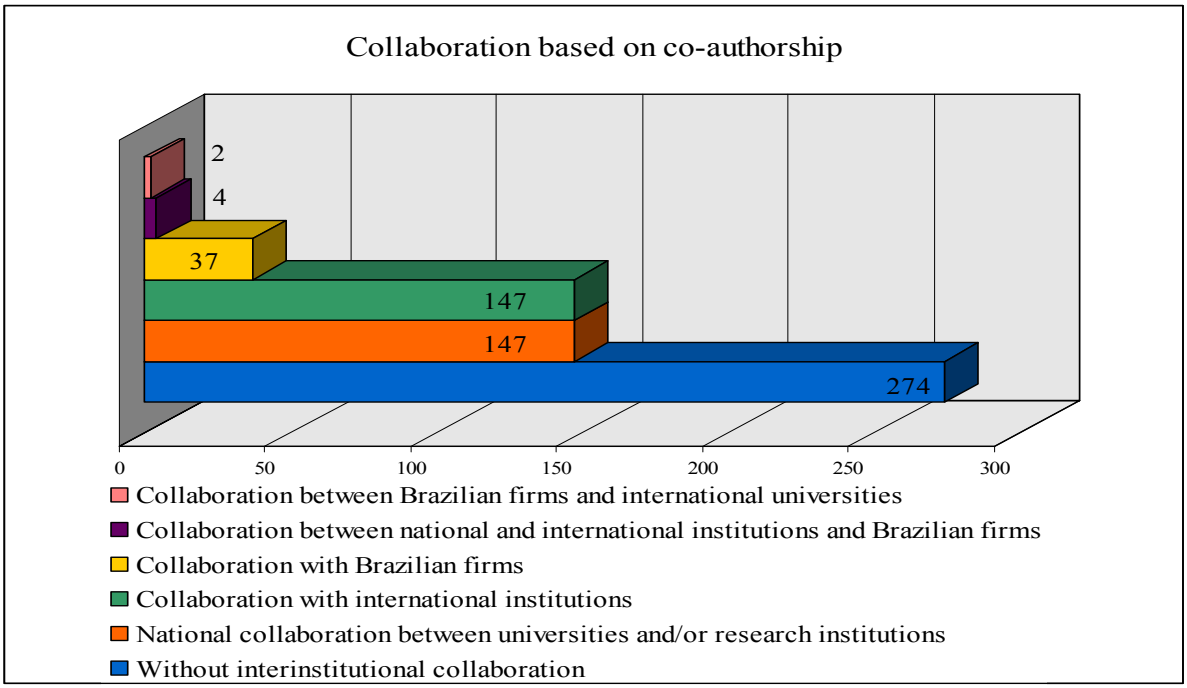

Figure 5. Collaboration based on co-authorship

Considering the interaction of mechanical engineering area with other knowledge areas – which are defined by the indexation of the journal in Web of Science database – the results showed that the principal interactions happen with the mechanics and thermodynamics areas. These two field of knowledge presented respectively 205 and 133 articles published concomitantly with mechanical engineering area. Figure 6 illustrates the interaction of mechanical engineering area with other knowledge areas.

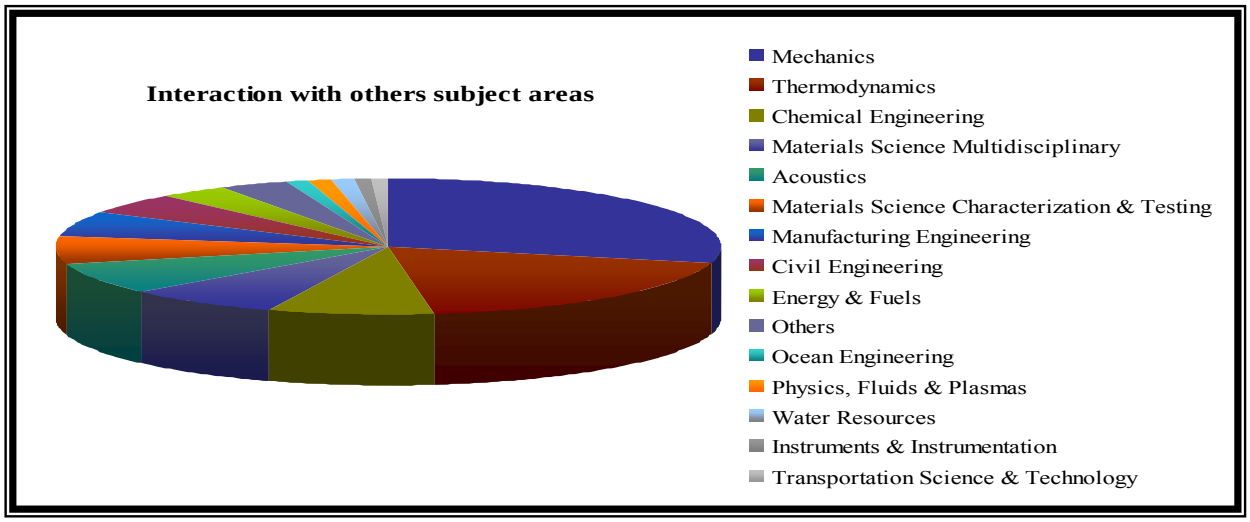

Figure 6. Interaction with other subject areas

The journals that published greater number of Brazilian articles in the mechanical engineering area are listed in Tab. 3, with the respective impact factor evaluated in 2007, corresponding to approximately 56% of the national scientific production indexed in Web of Science in the period analyzed.

Table 3. Relation of the 10 journals with more number of Brazilian articles published in period 2003-3008

Source title	**Total of articles published**	**Impact factor (2007)**
Journal of the Brazilian Society of Mechanical Sciences and Engineering	67	-
Drying Technology	55	1.171
International Journal of Heat and Mass Transfer	50	1.500
Journal of Sound and Vibration	39	1.024
Engineering Failure Analysis	33	0.565
International Journal of Machine Tools & Manufacture	25	1.120
Applied Thermal Engineering	22	0.868
International Journal of Fatigue	19	1.117
Latin American Journal of Solids and Structures	16	-
Fatigue & Fracture of Engineering Materials & Structures	15	0.726

The *Journal of Brazilian Society of Mechanical Sciences and Engineering* and the *Latin American Journal of Solids and Structures* didn't have impact factor analyzed in 2007. Considering the other journals it can be observed that the most of them presents impact factor around 1.0. The impact factor of the journals presented in Tab. 3 is from Journal Citation Report (JCR) and it represents the measure of the frequency with which the "average article" in a journal has been cited in a period of three years.

While the impact factor is frequently considered a measure to evaluate the importance of a journal, the number of times that an article is cited is used to estimate its importance. The articles that formed the universe of this research had a total of 1.374 citations. Without self-citations this number is reduced to 938. The ten articles with higher number of citations are related in Tab. 4.

Table 4. List of the 10 Brazilian articles with the higher number of citations in mechanical engineering area

Tittle of the article	**Publication year**	**Number of citations**
Turbulent flow in a channel occupied by a porous layer considering the stress jump at the interface	2003	29
Constructal flow structure for a PEM fuel cell	2004	21
Modeling of plate heat exchangers with generalized configurations	2003	21
Series solutions for a nonlinear model of combined convective and radiative cooling of a spherical body	2006	19
Heat transfer in enclosures having a fixed amount of solid material simulated with heterogeneous and homogeneous models	2005	16
Three-dimensional optimization of staggered finned circular and elliptic tubes in forced convection	2004	15
Nanotribological properties of amorphous carbon-fluorine films	2003	15
Numerical solution of turbulent channel flow past a backward-facing step with a porous insert using linear and nonlinear k-epsilon models	2005	14
Modelling the correlation between cutting and process parameters in highspeed machining of Inconel 718 alloy using an artificial neural network	2005	13
Refractive index of aerosol particles over the Amazon tropical forest during LBA-EUSTACH 1999	2003	13

The first five articles of the Tab. 4 were published in the *International Journal of Heat and Mass Transfer*. The other articles were published in the *International Journal of Thermal Sciences*, *Tribology Letters*, *Journal of Porous Media, International Journal of Machine Tools & Manufacture* and *Journal of Aerosol Science*.

5. CONCLUSION

Scientific publications are one of the indicators of result used to measure the scientific productivity. Often this indicator has been restricted to counting the number of the publications. Bibliometric studies of articles published, however, can provide a large set of information capable to contribute to a better understanding of the organization and dynamics of a specific field of knowledge.

This work presented aspects related to the Brazilian scientific production in the mechanical engineering area in the period 2003-2008. The results showed that number of Brazilian scientific articles in mechanical engineering has varied over the years; more than half of the scientific production involved inter-institutional partnership; 24% of the total of the articles were written in collaboration with international institutions; the average of authors per article is approximately 3 and the average of institutions is 1,7 per document published; the main interaction with others subject areas happens with mechanics and thermodynamics; the impact factor of the journals with greater number of articles published is around 1,0; and the articles that formed the universe of this research were cited 1.374 times.

Although of the large use, bibliometric studies present limitations (more details in Verbeek, 2002) should be complemented with others researches making use of different approaches and indicators. It is also important to consider that there are restrictions on the use of Web of Science to represent the scientific production of countries whose native language is not English. Another aspect is that there are few Brazilian journals indexed in this database. In Mechanical Engineering area, for example, the indexing of Journal of the Brazilian Society of Mechanical Sciences and Engineering was made only in 2008.

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