MICRO VIBRATION OF RUBBER TIP

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To my parents, wife and my children

"I took the one less traveled by,
And that has made all the differences"

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ABSTRACT

Cyclone technology have been widely use in the industry or home appliance for separating dust from the dirty air. High performance cyclone requires high efficiency cyclone to separate dust. To achieve high efficiency cyclone, the cyclone geometry need to be modified. One of the geometry that can be modified to improve the cyclone efficiency is the cyclone bottom diameter. The modification of this geometry is by making it smaller. Smaller cone bottom diameter will increase the risk of having dust to get clogged inside the cyclone. Thus the mechanism of dust removal during the cyclone operating condition have been developed. This mechanism using the flexible tip that will be attached to the cyclone. Due to its flexibility, the dust will not get clogged as the tip will vibrate and deformed when excited by cyclone internal high velocity. This study is focusing on the understanding the characteristic of the flexible tip that used in a vacuum cleaner appliance. The major area of this study is to simulate and analyze the natural frequency and mode shape of the flexible tip. A few variable parameter and geometries will be design for simulation. To comprehend the study, a finite element software is used. The different material of flexible tip and operational flowrate will be used along with the change in tip geometry mainly on the thickness, length and bottom diameter. The contraction mode shape that is beneficial for self-cleaning purpose will be identify.

ABSTRAK

Teknologi cyclone telah digunakan di dalam perkakasan industri dan perkakasan rumah untuk memisahkan habuk dari udara yang kotor. Bagi mendapatkan cyclone berprestasi tinggi, cyclone berkecekapan tinggi diperlukan. Geometri cyclone perlu diubah suai untuk mendapatkan cyclone berkecekapan tinggi dimana salah satu geometri yang boleh diubah suai adalah diameter bawah cyclone. Diameter bawah cyclone ini dikecilkan tetapi ini akan meningkatkan risiko habuk tersumbat di dalam cyclone. Oleh itu kajian ini dilakukan untuk menyelidik mekanisme penyingkiran debu semasa cyclone beroperasi. Mekanisme ini menggunakan hujung fleksibel yang akan dilekatkan di cyclone. Halaju yang tinggi di dalam cyclone akan menyebabkan hujung cyclone berubah bentuk kerana sifatnya yang fleksibel dan mengelakkan habuk daripada tersumbat. Kajian ini memberi tumpuan kepada memahami ciri-ciri hujung yang fleksibel yang digunakan dalam perkakas pembersih vakum. Kajian utama adalah untuk mensimulasi getaran hujung fleksibel ini bagi memahami frekuensi tabii dan bentuk modnya. Parameter operasi dan geometri hujung fleksibel ini diubah bagi tujuan simulasi. Untuk memahami kajian ini, perisian unsur terhingga digunakan. Bahan yang berbeza hujung fleksibel dan kadar aliran operasi akan digunakan bersama-sama dengan perubahan dalam tip geometri terutamanya kepada ketebalan, panjang dan diameter bawah. Mod penguncupan yang memberi manfaat bagi tujuan permbersihan sendiri akan dikenalpasti.

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LIST OF SYMBOLS

L	-	Length
Ø	-	Diameter
t	-	Thickness
V	-	Rotational velocity
NR	-	Natural rubber
SR	-	Silicone rubber
f_n	-	Natural frequency
f_d	-	Damped frequency
ξ	-	Damping ratio

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CHAPTER 1

INTRODUCTION

1.1 Background study

A large amount of our time spent in houses, workplaces or other buildings and therefore indoor spaces should be comfortable and hygienic. Gunho et al (2011) and Y.C Ann et al (2006) mention that indoor air contains more than twice the pollutants compare to outdoor air. This is due to air tightness, poisonous chemicals, food smells and ticks which are generated by the use of new materials and equipment in the building. A vacuum cleaner is a representative of home appliance for removing harmful materials from floors or carpets.

Gunho et al (2011) found that current commercial vacuum cleaner used in house consisted of paper filter, pre-filter and exhaust filter. Clean air is discharged to the atmosphere after go through all three level of filter whereby the dust or particle in the dirty air will be trap at each filter stage. Even though it is convenient to use, the vacuum cleaner suction pressure will rapidly decrease in proportion to the time of cleaning which the filter also need to be replaced periodically. Gunho et al (2011) and Y.C Ann et al (2006) have designed and tested cyclone for applying to vacuum cleaner.

Indoor dust is affected by the atmospheric aerosols and many fibers which are separated from the carpets, clothes and pets' fur. Gunho et al (2011) did mention that most of these types of dust size is larger than 2μm which can be easily removed using inertial forces. Thus a cyclone has been look as a suitable mechanism to collect and separate these type of dust by using its centrifugal force.

Emitting clean air is one of the criteria that a vacuum cleaner must have. Thus an international standard has been developed and most of first world countries require the vacuum cleaner manufacture to sell a vacuum cleaner that only emits 0.03% particles of size 0.3µm based on American Society of Testing and Materials (ASTM) F1977. This requirement need to be fulfil before the vacuum cleaner can be certified as High Efficiency Particulate Air (HEPA) vacuum cleaner. A higher efficiency vacuum cleaner need to be designed so that it can comply with the current requirement.

House hold dust consist a wide range of particle size as can be seen in Table 1.1. ASTM F1977 requirement do state a particular size of dust that a vacuum cleaner allows to emit and 0.3µm dust size is fall under Fine mode particle type. This require an optimization of the cyclone dimension parameters which will directly impact to its performance.

A lot of researches have been conducted in order to find the ideal configuration of a cyclone that will give high collection efficiency. Figure 1.1 shows the parameters that exist in the Stairmand high efficiency cyclone. The Stairmand high efficiency cyclone is one of the most popular cyclone designs and has been extensively studied and used as a standard in many cyclone studies (Dietz, 1981; Iozia & Leith, 1990; Kim & Lee, 1990; Liden & Gudmundsson, 1997; Hsiao et al, 2015). Tangential inlet that have in the Stairmand cyclone model is preferable since it give an advantage in design space. At least nine geometrical parameters have been extensively studied by lot of researches and most of it have an impact to the cyclone performance either significant or not.

Table 1.1: Typical parameters of atmospheric and diesel aerosols [Y.C. Ann et al (2006)]

Particle type	Mass mean diameter, µm	Geometric standard deviation	Mass concentration, µg/m^3
Fine mode	0.18-0.36	1.66-2.16	2.07-38.4
Coarse mode	5.7-2.5	-2	6.2-205
Diesel mode	0.15-0.5	1.62-2.1	3.85-36.3

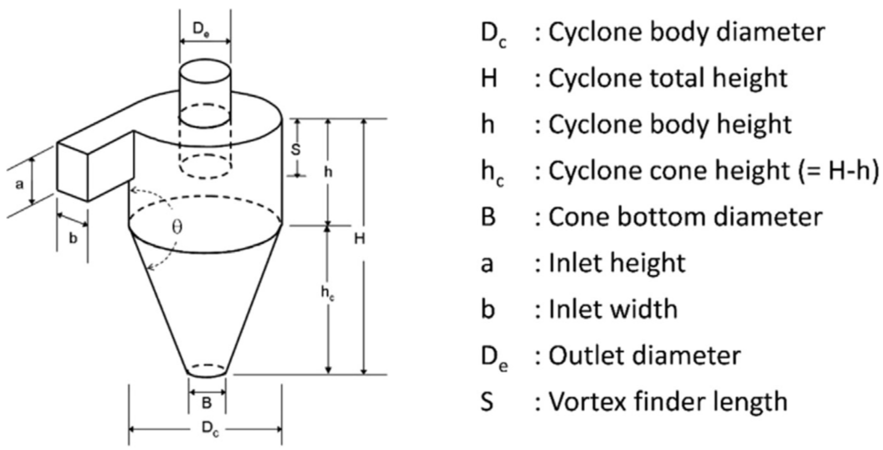

Figure 1.1: Conventional cyclone of tangential flow [Hsiao et al (2015)]

The standard Stairmand high efficiency cyclone dimensional ratio as shown in Table 1.2. Other ratio that have been used by different researches are discussed in next chapter

Table 1.2: Dimensional ratios of Stairmand cyclone [Hsiao et al (2015)].

Inlet		Vortex finder		Cyclone body and cone		
a/D_c	b/D_c	D_e/D_c	S/D_c	h/D_c	H/D_c	B/D_c
0.52	0.2	0.52	0.6	1.6	4	0.36

Each Hsiao et al (2015), Xiang et al (2000) and Gimbun et al (2005) in their research have found out that the cone bottom diameter, B, have an effect to the cyclone collection efficiency while other parameter is constant. Bryant & Silverman (1983) in their research have suggested the possible consequences of tuning this dimension which if exceeding certain limitation can cause the vortex to touch the cone wall. The dust will re-entrain into the vertical vortex which can lead to cone blocking. This condition will definitely decrease the cyclone collection efficiency but most of the study suggested that smaller dimension is an option in order to gain higher efficiency. In small cyclone design used in the vacuum cleaner, the smaller cone bottom dimension is needed due to space constraint. Thus the cyclone has to be small in size and shall have no cone blocking issue during operational.

To achieve high efficiency in a small cyclone, the cone tip must be considerable small and this lead to high possibility of cone blocking. This limitation has brought the cyclone technology into another perspective where the cyclone is requiring to be able to do self-cleaning whenever the cone gets block. The concept of vibration and mode shape change have been applied to the conventional cyclone technology. A rubber part has been designed with small cone bottom dimension which enough able to produced high efficiency cyclone but at the same time vibrating at certain frequency when excited at certain operational flowrate.

The combination of vibration and flow in a cyclone have never been studied and this have been look by the author as the breakthrough technology that enable the cyclone to achieve much higher efficiency while have no risk to cone blocking especially for a cyclone that used in a vacuum cleaner.

1.2 Problem statement

Cyclone performance especially collection efficiency depends on two category parameters which are geometrical dimension and the operational flow rate. These parameters have to be tuned in order the cyclone to perform at its design requirement. The vibration of the flexible part that attach to the cyclone depends on the excitation of the flow that been introduced to it. Since small cyclone in a vacuum cleaner have a limited operational flow, the vibration of this flexible part also depend on it. Thus to ensure self-cleaning of the flexible part of vacuum cleaner, minimum flow rate and frequency to generate required mode shape of the part need to be determined and analysed.

1.3 Objectives

a. To investigate the vibration characteristics of natural rubber flexible cone tip of standard dimension by conducting Finite Element Analysis.
b. To determine the frequency of cone tip of different cone bottom diameter at different operational flow rate by Finite Element Analysis.

1.4 Scope of work

1. Simulation study using FEA
2. Cone made of natural rubber
3. Results verified with experimental measurement
4. Variable parameters: Cone geometry & flowrate

REFERENCES

1. A.C. Hoffmann, A.V. Santen, R.W.K Allen, Gas Cyclone and Swirl Tubes (2008) 2nd ed Springer.

2. A. C. Hoffmann, R. D. Jonge, H. Arends, C, Hanrats (1995), Evidence of natural vortex length and its effect on the separation efficiency of gas cyclones, Filtration and Separation, 32, 799-804

3. A.C. Hoffmann, H. Arends, H. Sie, An experimental investigation elucidating the nature of the effect of solids loading on cyclone performance, Filtration Sep 28 (3) (1991) 188-193

4. A.C. Hoffmann, A.V. Santen, R.W.K. Allen, Effects of geometry and solid loading on the performance of gas cyclone, Powder Technology 70 (1) (1992) 83-91

5. Ahn Y.C., Jeong H.K., Shin H.S., Hwang Y.J., Kim G.T., Cheong S.I., J.K. Kim Lee & Kim C., (2006), Design and performance evaluation of vacuum cleaners using cyclone technology, Korean J. Chem. Eng 23 (6) 925-930

6. Avci. A & Karagoz. I, Effects of flow and geometrical parameters on the collection efficiency in cyclone separators. Journal of Aerosol Science (2003) 34 (7) 937~955

7. Bryant H.S, Silverman R.W, Zenz F.A, How dust in gas affects cyclone pressure drop (1983), Hydrocarbon Processing, 62 (6), 87~90

8. Belvins R.D., Flow Induced Vibration. Van Nostrand Reinhold Co., New York (1990)

9. D.L. Hertz, Jr, A.C. Farinella, Shore A Durometer and Engineering Properties, The New York Rubber Group (1998)

10. Dietz, P.W., Collection efficiency of cyclone separators, AIChe Journal (1981) 27(6), 888-892

11. E. Mushelknautz, M. Trefz, Design and calculation of higher and highest loaded cyclones, Proceedings of Second World Congress on Particle Technology, Kyoto, Japan, 1990.

12. Gunho Ha, Eungdal Kim, Youngsoo Kim, Jaekeun Lee, Youngchull Ahn, Donggyu Kim, A study on the optimal design of a cyclone system for vacuum cleaner with the consideration of house dust, (2010), Journal of Mechanical Science and Technology 25 (3)(2011) 689~694

13. Gimbun J., Chuah T.G., Thomas S.Y. Choong, A. Fakhru'l-Razi Prediction of the effects of cone tip diameter on the cyclone performance, (2004), Journal of Aerosol Science 36 (2005) 1056-1065

14. Hsiao, Huang, Hsu, Chen, Chang, Effects of the geometric configuration on cyclone performance (2015). Journal of Aerosol Science 86 (2015) 1-12

15. Haig C.W., Hursthouse A., McIlwain S., Sykes D., The effect of particle agglomeration and attrition on the separation efficiency of a Stairmand cyclone, Powder Technology 258 (2014) 110-124

16. H. Y. Gou, M. Lou, Effect of internal flow on vortex-induced vibration of risers, Journal of Fluids and Structures 24 (2008) 496-504.

17. Inman, Daniel J., Engineering Vibration, Prentice Hall (2001), ISBN 0-19-514246-2

18. Ioza, D.L, Leith D., The logistic function and cyclone fractional efficiency, Aerosol Science and Technology, (1990) 12(3), 598-606

19. J.C Kim, K.W. Lee, Experimental study of particle collection by small cyclones, Aerosol Science Technology, 12 (1990) 1003-1015

20. J, Paiva, R. Salcedo, P. Araujo, Impact of particle agglomeration in cyclones, Chemical Engineering Journal 162 (2) (2010) 861-876

21. J. Reppenhagen, J. Werther, Catalyst attrition in cyclones, Powder Technology 113 (1-2) (2000) 55-69

22. J.P. Den Hartog, Mechanical Vibrations, Courier Corporation (2013), ISBN 0-486-64785-4

23. Kenny L.C., Gussman R. A., A direct approach to the design of cyclones for aerosol-monitoring applications, Journal of Aerosol Science (2000) 31 (12), 1407-1420

24. Lim K.S., Kim H.S., Lee K.W., Characteristics of the collection efficiency for a cyclone with different vortex finder shapes. Journal of Aerosol Science (2003) 35 743~754

25. Liden G, Gudmundsson A, Optimization of a cyclone to the 1993 international sampling convention for respirable dust, Applied Occupational and Environmental Hygiene (1997) 11(12), 1398-1408

26. M. Marinuc, F. Rus, The effect of particle sizes and input velocity on cyclone separation process, Bulletin of the Transilvania University of Brasov, Series II: Forestry, Wood Industry, Agricultural Food Engineering, Vol. 4 (53) No. 2 (2011)

27. M.E. Moore, A.F. McFarland, Performance modeling of single-inlet aerosol sampling cyclones, Environment Science Technology, 27 (1993) 1824-1848

28. M. Ghadiri, Z. Zhang, Impact attrition of particulate solids. Part 1: A theoretical model of chipping, Chemical Engineering Science 57 (17) (2002) 3659-3669

29. Material Data Book, Cambridge University Engineering Department (2003)

30. Niki Gopani, Akshey Bhargava, Design of High Efficiency Cyclone for Tiny Cement Industry, International Journal of Environmental Science and Development Vol. 2, No. 5 (2011)

31. N. Cagney, S. Balabani, Fluid force acting on a cylinder undergoing streamwise vortex-induced vibrations, Journal of Fluid and Structures 62 (2016) 147-155

32. R.I. Salcedo, Collection efficiencies and particle size distributions from sampling cyclones – comparison of recent theories with experimental data, Can. J. Chemical Engineering 71 (1993)

33. R. Roy, Case study of creativity in innovative product development, Des. Stud, 14 (4) (1993) 423-443

34. Xiang R., Park S.H., Lee K.W., Effects of cone dimension on cyclone performance, Journal of Aerosol Science 32 (2001) 549-561

35. Xiangxi Han, Wei Lin, Youhong Tang, Chengbi Zhao, Karl Sammut, Effects of natural frequency ratio on vortex-induced vibration of a cylindrical structure, Computers and Fluids 110 (2015) 62-76

36. Zhu Yifang, Lee K.W., Experimental study on small cyclones operating at high flowrates. Journal of Aerosol Science (1999) Vol. 30, No. 10 1303~1315