


I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of the Bachelor of Mechanical Engineering (Structure and Material).

Signature : 
Name of Supervisor : Ir. Tan cheo Fai
Date : 27.05.2006

MECHANISM DESIGN AND ANALYSIS OF HVAC INSPECTION CRAWLER


MOHD AZHAR B. MOHD ZUBIR

This thesis report submitted to faculty of mechanical engineering in partial fulfillment of the requirement for the award of Bachelor degree of Mechanical Engineering
(Structure & Material)

Faculty Of Mechanical Engineering
Koleh Universiti Teknikal Kebangsaan Malaysia

JUNE 2006

I hereby the author, declare this report entitled "MECHANISM DESIGN AND ANALYSIS OF HVAC INSPECTION CRAWLER" is my own except for quotations and summaries which have been duly acknowledged.

Signature : 
Author : MOHD AZHAR ZUBIR.
Date : 29/5/06

ACKNOWLEDGEMENT

First of all I would like to thanks to my PSM supervisor, Mr Tan Chee Fai, supervisor and the most important person who give me fully trustworthy to run this project. He is the person who guide me and give an encourage advise through all aspect during this project. He teaches me on how to get an idea and the flow of this project progression. Without his advice and attention, this project will be nothing at all. I also would like to give a special thanks to Mr. Johari Md Yusoff, Sr Charge man of Techart Sdn Bhd for his knowledge and supervision during my interview with him. This person gave me lot of his experience and guides me on basic knowledge of ducting and maintenance. My appreciation also goes to Mr Ibrahim Jaal, Technical Officer, MTB/CP/SAT engineering department of Malaysia Airport Berhad (MAB) with his co-operation in getting a ducting plan and advice. Thanks to him for his trustworthy and support me to run this project. Not forgotten, lot of thanks to all individual who involve and support me like Mr Mohd Zubir Omar (Muda Paper Mill Sdn Bhd), Miss Suzana Hj Shamsuddin (BESCOM Technologies Sdn Bhd), Mr Shamsul Anuar (KUTKM) and Mr Ahmad Rivai(KUTKM) and all my friends.

ABSTRACT

Usage of robotic expansion as additional element in any various work recently grow rapidly. This phenomenon happens by existence of many research and development (R&D) for the robot of individuals and parties. Increasing of many researches especially in robotic technologies make most of job and duty have been done by assistance of robot and technologies. Some job only can be perfectly done by technologies. According to the existence of new technologies also affect the method of HVAC inspection. The problem of ducting inspection is un-ability of human to crawl along the ducting to do inspection. This is especially to located the ducting crack or find any problem along the ducting. A new technology is using a robotic crawler to be human eyes to inspect the critical location on the ducting. Various crawlers enter the global market with high value and price. The mechanism of some crawler remains the same but the difference is the body and chassis design. For this project will develop new mechanisms that can apply to the crawler. A simple mechanism is used to reduce the cost but high effective product.

ABSTRAK

Penggunaan robot sebagai elemen tambahan dalam pelbagai kerja kini semakin meningkat. Fenomena ini berlaku kerana kewujudan pelbagai kajian dan pembangunan robot oleh individu atau pihak-pihak tertentu. Peningkatan bilangan kajian terutama dalam teknologi robot membuatkan kebanyakan kerja dan tugas dilakukan dengan bantuan robot dan teknologi. Malah, sebilangan kerja hanya boleh dilakukan dengan lengkap oleh teknologi. Kewujudan teknologi baru ini turut dirasai oleh proses pemeriksaan HVAC. Masalah utama dalam proses pemeriksaan saluran HVAC adalah ketidak-bolehan manusia untuk memasuki sepanjang saluran itu untuk membuat pemeriksaan. Terdapat juga aplikasi kamera kabel untuk pemeriksaan ini. Kaedah terbaru dalam pemeriksaan salur HVAC ini adalah menggunakan perangkak robot atau '*robotic crawler*' yang bertindak sebagai 'mata manusia' bagi memeriksa salur HVAC tersebut. Pelbagai jenis crawler telah berada dalam pasaran. Hampir keseluruhan crawler ini menggunakan mekanisma yang sama tetapi berbeza dari segi badan dan casis. Pada project ini, ia akan memaparkan sebilangan mekanisma baru yang dibagunkan untuk di aplikasikan pada crawler tersebut. Mekanisma mudah digunakan untuk mengurangkan kos tetapi menghasilkan produk yang effective.

CONTENT

CHAPTER	TOPIC	PAGES
	VERIFICATION OF TITLE	i
	DECLARATION	ii
	ACKNOWLEDGEMENT	iii
	ABSTRACT	iv
	ABSTRAK	v
	LIST OF FIGURE	ix
	LIST OF GRAPH	xiii
	LIST OF TABLE	xiv
	LIST OF APPENDIX	xv
1	INTRODUCTION	
	1.1 BACKGROUND	1
	1.2 DUCTING INSPECTION & CLEANING	1
	1.3 PROBLEM STATEMENT	2
	1.4 OBJECTIVE	3
	1.5 SCOPE OF WORK	3
2	LITERITURE REVIEW	
	2.1 DUCTING & HVAC SYSTEM	4
	2.1.1 AIR CONDITIONING DUCTING	5
	2.1.2 HEATING DUCTING	7
	2.1.3 VENTILATION DUCTING	8

2.2	DUCTING POSITION AND TYPE	11
2.2.1	FABRIC DUCTING	13
2.2.2	POLYTHENE DUCTING	14
2.3	DUCTING MAINTAINANCE	15
2.3.1	INSPECTION	16
2.3.2	CLEANING	17
2.4	NADCA STANDARD	18
2.5	EXISTENCE CRAWLER IN MARKET	20
2.6	BASIC OF ELECTRIC AC/DC MOTOR	34
2.7	POWER TRANSMIT SYSTEM	35
2.9	BELT	40
3	METHODOLOGY	42
4	RESULT	
4.1	DESIGNS OF THE MECHANISM	45
4.1.1	MODEL HC01	46
4.1.2	MODEL HC02	50
4.1.3	MODEL HC03	54
4.1.4	MODEL HC04	58
4.1.5	MODEL HC05	62
4.1.6	MODEL HC06	66
4.2	ANALYSIS	70
4.2.1	GEAR CALCULATION HC01, HC02 & HC04	71
4.2.2	GEAR & PULLEY CALCULATION FOR MODEL HC03	74
4.2.3	GEARING CALCULATING FOR MODEL HC05	77

4.2.4	GEARING CALCULATING FOR MODEL HC06	81
4.2.6	CONTACT STRESS ANALYSIS	87
4.2.7	SPROCKET & CHAIN ANALYSIS FOR MODEL HC02	92
4.2.8	WHEEL & BELT ANALYSIS FOR MODEL HC04	95
4.2.9	STATIC ANALYSIS OF BEARING REACTION.	98
4.2.10	STATIC ANALYSIS OF WHEEL	99
5	DISCUSSION	
5.1	GEAR & PINION ROTATIONAL VELOCITY	101
5.2	OUTPUT ROTATIONAL SPEED	103
5.3	MAXIMUM PRESURE CONTACT	105
5.4	MAXIMUM SHEAR STRESS AT WHEEL	106
5.5	PINION AND GEAR COMBINATION	107
5.6	DESIGN SELECTION	109
6	CONCLUSION	
6.1	CONCLUSION	110
6.2	RECOMMENDATION	110
	REFERENCE	111
	APENDIX	113

LIST OF FIGURE

	TITLE	PAGES
FIGURE 1	the hole located at ducting	6
FIGURE 2	The hole located at heating ducting	8
FIGURE 3	Air movements in Ventilation ducting	9
FIGURE 4	Air movements in displacement ventilating	10
FIGURE 5	Ducting locations for under ceiling model	12
FIGURE 6	Location of ducting for upper ceiling model.	12
FIGURE 7	Metal ducting layers	13
FIGURE 8	Flow Meter	16
FIGURE 9	Camera and hosting for ducting inspection	16
FIGURE 10	MICRO VGTV crawlers	21
FIGURE 11	Specification of MICRO VGTV crawlers	21
FIGURE 12	Model of DESERT STORM crawler.	22
FIGURE 13	DESERT STORM cleaning brush	22
FIGURE 14	Specification of Desert Storm.	23
FIGURE 15	Wolverine Robots	24
FIGURE 16	Specification of Wolverine robot	24
FIGURE 17	CY-BOT crawler	26
FIGURE 18	LWT PIT HOG™ Robotic Crawler	28
FIGURE 19	HS-475HB Servos Specification	29
FIGURE 20	HS-645MG Servos Specification	30
FIGURE 21	NOMAD HDATS crawler	30
FIGURE 23	Versa Trax 100 Crawler	33
FIGURE 24	the Pipe Crawler	34

FIGURE 25	basic layouts of electric motor	35
FIGURE 26	Spur Gear	36
FIGURE 27	Helical Gear	37
FIGURE 28	Bevel Gear	37
FIGURE 29	Ring Gear	38
FIGURE 30	Roller chain	38
FIGURE 31	Belt	40
FIGURE 32	Gant Chart for the project	44
FIGURE 33	Model HC01	46
FIGURE 34	Interior design of mechanism for HC01 model	47
FIGURE 35	Isometric View of HC01 Mechanism	48
FIGURE 36	Front View of HC01 mechanisms	48
FIGURE 37	Top View of HC01 mechanisms	48
FIGURE 38	Spur Gear 16T	49
FIGURE 39	Spur Gear 14T	49
FIGURE 40	180mm Shaft	49
FIGURE 41	BEARING	49
FIGURE 42	130mm Diameter Wheel	49
FIGURE 43	HC02 Model	50
FIGURE 44	Interior Mechanism of HC02 model	51
FIGURE 45	Front View of HC02 the Mechanism	52
FIGURE 46	Top View of HC02 Mechanism	52
FIGURE 47	SPUR GEAR 16T	53
FIGURE 48	SPURGEAR 14T	53
FIGURE 49	SHAFT	53
FIGURE 50	BEARING	53
FIGURE 51	SPROCKET	53
FIGURE 52	HC03 Mechanism model	54

FIGURE 53	Isometric View of HC03 Model	55
FIGURE 54	Front View of the Mechanism	56
FIGURE 55	Side View of the mechanism	56
FIGURE 56	Top View of the Mechanism	56
FIGURE 57	SPUR GEAR 14T	57
FIGURE 58	BELT PULLEYS	57
FIGURE 59	SHAFT	57
FIGURE 60	FLAT BELT 20mm WIDTH	57
FIGURE 61	BEARING	57
FIGURE 62	Wheel for HC03 model	57
FIGURE 63	HC04 Model	58
FIGURE 64	Isometric View of the HC04 mechanism	59
FIGURE 65	Front view of the HC04 mechanism	59
FIGURE 66	Side view of the HC04 mechanism	60
FIGURE 67	Top View of the HC04 Mechanism	60
FIGURE 68	SPUR GEAR 16T	61
FIGURE 69	14T SPUR GEAR	61
FIGURE 70	Shaft for HC04 model	61
FIGURE 71	BEARING	61
FIGURE 72	Wheel for HC04 model	61
FIGURE 73	HC05 model	62
FIGURE 74	Layout of the HC05 mechanism	63
FIGURE 75	Isometric view of the HC05 mechanism	64
FIGURE 76	Front view of the HC05 mechanism	64
FIGURE 77	Top view of the HC05 mechanism	64
FIGURE 78	spur gear 14T	65
FIGURE 79	Spur Gear 28T	66
FIGURE 80	Shaft for model HC05	66

FIGURE 81	Bearing	66
FIGURE 82	Wheel for HC05 model	66
FIGURE 83	Force Diagram for shaft	86
FIGURE 84	Load Diagram for Shaft	87
FIGURE 85	Contact of Wheel to the base (Ducting)	87
FIGURE 86	Force exerted and the 'a' position	88
FIGURE 87	Sprocket & chain diagram for model HC02	92
FIGURE 88	Wheel & Chain diagram for model HC04	95
FIGURE 89	Shaft, gear and bearing mating diagram	98
FIGURE 90	free body diagrams for shaft, gear and bearing mating	98
FIGURE 91	Wheel and shaft mating diagram	99
FIGURE 92	Free body diagrams for wheel and shaft mating	100
FIGURE 93	Selection model for mock up.	109

LIST OF GRAPH

	TITLE	PAGE
GRAPH 1	graph of 'a' value vs. load	90
GRAPH 2	output gear speed of variable pinion input.	102
GRAPH 3	Crawler velocities for variable rotational velocity input	104
GRAPH 4	Graph of maximum pressure for variable crawler's weight	106
GRAPH 5	Graph of maximum shear stress for variable crawler's weight.	107

LIST OF APPENDIX

	PAGES
Appendix A- Specification of spur gear 14T	113
Appendix B – Specification of spur gear 16T	114
Appendix C – Specification of spur gear 28T	115
Appendix D –Specification of spur gear 32T	116
Appendix E – Specification of belt pulley	117

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

This project is for usage of any air conditioning maintenance team in various building especially HVAC maintenance team. This project is a development in HVAC inspection, maintenance and commissioning.

1.2 DUCTING INSPECTION AND CLEANING

Normally ducting inspection will be done first before do the cleaning progress. But the inspection also will be done for any mounting like to check the malfunction of the ducting, to check any crack etc. This is because the inspection is the method to measure the usage of cleaning. Even for some building, the weekly, monthly or permanently cleaning can be provide but the inspection must be done before the cleaning. This is to view in the ducting for its condition either the cleaning should be done or not at the time. This step can reduce the building cost maintenance.

The inspection also used to find and solves a problem in the duct duty. Like some example of air conditioning leakage problem at KLIA. The leakage happens in the ducting but the actual position of the leakage unable to locate.

The cleaning process is important to maintain the duct in good conditioned and cover its long lasting or life span. Cleaning should be done after an inspection done. How can the cleaning run up without make an inspection before and after the cleaning process? This might be use. But for some building owner, they have to know the progression of the cleaning like before and after the cleaning. This is more to picture or some view of the internal ducting.

However, in some inventor and opinion there is no need for ducting cleaning according to its compact custody and protection. Ducting system is equipped with air filter at the resource. This filter will entrap the dust and hazard as well. The cleaning process only need for this filter by replace it in some period. Thus, the cleaning of the ducting is not an important step for the building safety environment. But, this progress can be done if asked to. The cleaning is suggested by many healthy organizations like OSHA, ASHRAE, and NADCA etc. But for this project I emphasizing on inspection method only.

1.3 PROBLEM STATEMENT

HVAC ducting condition can be done with direct visual inspection. Direct visual inspection means the inspector will check ducting existing. This method only used for existing ducting like under ceiling module. The visual inspection only can inspect the condition of the ducting externally. But the problem occurs in upper ceiling module where it's a difficulty for the inspector to climb in the ceiling and inspect for the whole ducting.

The second problem is on progress to inspect internal condition of the ducting which might full of dust and fragile. This problem can be solves using a cable cam camera or push camera but the distance and it's efficiently is not too good. By using a cable camera, it too difficult to move it to the ducting and don't have a clearly view. The inspector needs to push the camera and reel into the duct.

Some manufacturer and robot expertise have created and produced the moving robot crawler which can be used for inspection in ducting. However the existence product is more compactable and cost more. The entire product is more on flat smooth tracks. There are several robotic crawlers using a tank wheel mechanism but the weight is not suitable and some of them using an ordinary round wheel. This kind of crawler can be used just in smooth flat tracks but the problem happen whenever the crawler moving on non-tabular track.

1.4 OBJECTIVE

This objective of this project is to design a new model of HVAC inspection crawler's mechanism. Beside, this project also does an analysis of the designed mechanism.

1.5 SCOPE OF WORK

In this project, the scope of work will cover a design of new mechanism and analysis. In order to fulfill the objective, the existing crawler in market will be a reference to design the new model and mechanism.

CHAPTER 2

LITERITURE REVIEW

2.1 DUCTING & HVAC SYSTEM

Almost every commercial building and office has an air conditioning unit. It has become a necessity of modern life. For a small office, a window air conditioning unit will suffice. These are self contained units which do not need much skill to install. Nowadays, the trend is to use split air conditioning units in the average sized office and home because they are quieter. However, there are some amounts of drilling, joining of tubes, vacuuming, charging of refrigerant gas, and other installation works to be done. Larger buildings make use of Central Air Conditioning. The basic concept of cooling or heating remains the same. However, the system can be designed to be very complex if necessary. Automatic temperature controls, microprocessor and operation logic controls, building automation controls, and other smart features have made some systems beyond the handling capability of many normal technical people. New types of refrigerant are constantly being developed to produce minimal damage to the environment. New materials have to be used to work with the new refrigerants. Better efficiency methods are adopted for maximum energy savings. Air conditioning is more than just cooling or heating the environment.

In central air conditioning system, usage of chill water is one of important item. The system used chill water from chiller as coolant fluids to reduce the air temperature. Some of the building used a cooling tower to provide chill water while some building used a chiller. The cooling process will be done in Air Handling Unit room (AHU) and the cool air will be transmitting using a ducting. Ducting is the most important and particular component. Ducting act like a conductor and distributor of the cooled air from source to sink like rooms and hall. There 3 type of ducting:

- Air conditioning ducting
- Heating ducting
- Ventilating ducting

According to this 3 type of ducting a general named call heating, ventilating and air conditioning (HVAC) ducting.

2.1.1 AIR CONDITIONING DUCTING

Air conditioning ducting is the most economic and efficient method of distributing warm and cold air. A typical ducting system consists of one or more inflatable ducts suspended overhead from steel wires. Rows of small holes in the sides of the ducts produce jets of air, with enough throw to create continuous gentle air movement throughout the building. Ducting is compatible with most fans, heaters, air conditioners, air handling units, etc. Its adaptability and very low cost make it suitable for use as heating, cooling or ventilation ducting in a wide range of buildings and industries. Ducts are the most cost effective and efficient method of conveying cold air from point to point, and distributing it where it's needed. Most or some of ducts are manufactured from lightweight polythene, and are compatible with most air conditioners, evaporative coolers and fans. Air conditioning ducting is used to improve cold air distribution. Without air conditioning ducting the effect of a fan, air conditioner or cooler is limited to a small area immediately in front of the air outlet. Attaching

ducting allows the cold air to be directed to specific 'hot spots' to provide localized cooling, or diffused over a wide area to reduce temperature gradients. It's also Reduce air velocity by reduced air speed stops cold drafts, and lowers noise levels. Air conditioning ducts are usually suspended overhead from steel wires. Rows of small holes in the sides of the ducts produce jets of cold air that mix with the warmer room air before falling to floor level. Leading to draft free air movement throughout the building and reduced temperatures. Holes normally placed at 10 o'clock and 2 o'clock provide draft free air diffusion. For wide building the hole are placed at 9 o'clock and 3 o'clock. (Please refer to FIGURE 1)

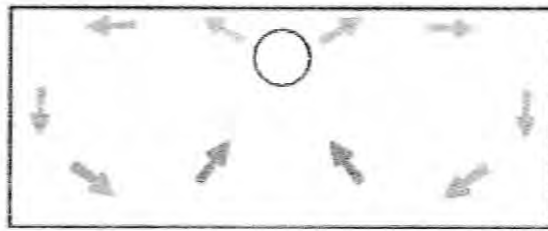


FIGURE 1 The hole located at ducting

In very hot environments, such as foundries, commercial laundries, bakeries, etc. the holes are moved to 4 and 8 o'clock. The jets of cold air are now directed downwards, displacing hot air which is forced up and away from floor level. By using numerous small jets the air velocity is kept low, ensuring the workforce do not complain of uncomfortable cold drafts. Sections of plain and perforated air conditioning ducting can be connected to portable air conditioning units to provide spot cooling. This is very popular where cooling a large area is uneconomic or unnecessary. Cold air is discharged precisely where needed, keeping energy costs low.

2.1.2 HEATING DUCTING

Heating ducts are the most adaptable and efficient method of distributing and diffusing warm air. Heating ducts are compatible with most warm air heaters and air handling systems, and are used in place of metal ductwork to improve air distribution and reduce temperature gradients.

Heating ducts are designed for use in buildings with large open roof spaces, as found in factories, warehouses, workshops etc. They are suspended overhead from thin steel wires. Holes in the sides of the ducts create jets of warm air, which are directed downwards, where they mix with the cold air below eradicating temperature gradients and producing uniform temperatures.

Heating ducts help to reduce heating bills in several ways:

- Reduced heat loss through the roof - By creating air movement throughout the building, temperatures in the roof space are reduced, which in turn lowers the heat loss through it.
- Reduced stratification - Thermostats can be set to a lower level. Constant air mixing reduces the build up of pockets of cold air and stratification, creating a uniform temperature throughout the building.
- Reduced condensation - Improved air distribution, prevents layers of cold air and condensation forming on walls, doors, windows, shelves, etc.
- Spot heating - Holes in the heating ducts are placed only where needed, heating occupied areas without wasting energy on storage areas, loading bays, etc.

For a modern building with 5m (16ft.) eaves savings of up to 10% per annum are possible leading to payback is less than two years. Because of air stratification, savings increase with the height of the building. For the wide buildings - one or more heating ducts are suspended overhead on lightweight steel wires.

The heating ducts have rows of large diameter holes positioned at 4 and 8 o'clock (or 5 and 7 o'clock) forcing powerful jets of warm air towards floor level. (Please refer to FIGURE 2). While for the narrow buildings or low level ducts - smaller holes is used. It's positioned at 3 and 9 o'clock to create a gentler diffused air discharge. This reduces the air velocity, stopping strong jets of warm air coming in contact with the workforce.

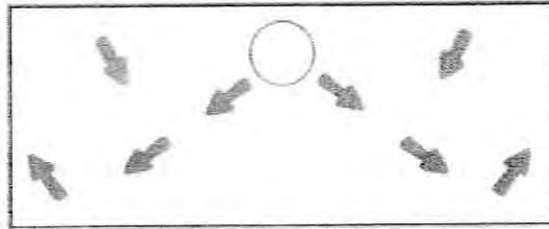


FIGURE 2 The hole located at heating ducting

2.1.3 VENTILATION DUCTING

Ventilation ducting is the most economic, accurate and efficient method of conveying and diffusing fresh air. Manufactured from polythene tubing, ventilation ducting is used in a wide range of industries and applications including:

- Emergency services - delivering fresh air into collapsed buildings
- Petrochemical industry - ventilating storage tanks and pits undergoing maintenance
- Site maintenance - providing fresh air to welders working in enclosed areas
- Agriculture - delivering fresh air into animal houses, mushroom growing rooms, etc.

Ventilation is also used and needed in animal houses to:

- Remove excess heat - High temperatures are unpleasant for workers and animals, although mature cattle and sheep are tolerant of high ambient temperatures, young animals are less so, and air movement helps by encouraging the bodies' natural cooling system.
- Reduce damage by moisture - the average cow breathes out 5 gallons of water vapor a day. Ventilation prevents it settling on surfaces of the structure and damaging it.
- Remove noxious gases - Reduces respiratory problems and pneumonia, and improves the health of animals and workers alike by removing ammonia, hydrogen sulfide and methane.
- Discourage flies - flies prefer still air

A typical installation consists of an axial fan suspended in the roof space at one end of the building which draws fresh air in from outside. Ventilation ducting is connected to the fan and runs down the length of the building (please refer FIGURE 3). Holes cut into the sides of the ventilation ducting distribute the fresh air in a series of high pressure jets.



FIGURE 3 Air movements in Ventilation ducting

Displaced air leaves the building via holes in the structure, cracks, open doors or windows etc. Where necessary additional pressure operated vents should be installed, manufactured from aluminum or plastic, they have flaps which are lifted open by pressure from the inside air as it escapes but stay firmly closed when outside winds blow on them. The total area should be two to three times that of the fan.