

Study of Measurement and Control Aspects of Wind Tunnel

V.L. Kakate¹, D S Chavan², P.B Karandikar³, Niraj Mahulkar⁴

PG student, Electrical Engineering Department, BVDU COE, Pune, India^{1,4}

Associate Professor, Electrical Engineering Department, BVDU COE, Pune, India²

Associate Professor, Army Institute of Technology, Pune, India³

Abstract: Wind energy is one of the cost effective renewable energy source. It is generated by horizontal axis and vertical axis wind turbines. Wind speed should be in the range of 5m/s to 15m/s for its effective generation. Low speed wind turbine development is in progress. Many leading research organizations, research labs in universities and wind energy industries around the globe are trying to develop micro or mini wind tunnel for feeding the electricity needs of urban houses. Energy generation from wind involves lot of electrical, mechanical and wind related parameters. Study of these parameters and their effect on electrical output is research topic for many decades. Testing of wind turbine with variation in wind parameters, electrical machines and tower type etc. are the major problems. Research centres of many establishments of leading companies such as suzlon has facilities to do such research work. Academic fraternity finds extremely difficult. One of the options is computer simulation. Wind tunnels of various sizes are available in leading educational organizations and companies. However most to them are of small and medium sizes and are suitable for performing specific tests pertaining to the particular product. This paper focuses on study of various wind tunnel parameters, types of tunnels, wind tunnel size and shape, air delivery, inlet-outlet dimensions and length of wind tunnel. Cooling of air, type of testing which can be performed etc are presented in this paper by keeping the major focus on electrical aspects in setting up wind tunnel.

Key words: Wind energy, Wind tunnel, Exhaust fan

I. INTRODUCTION

A wind tunnel is a tool used in aerodynamic research to study the effects of air moving past solid objects. A wind tunnel consists of a closed tubular passage with the object under test mounted in the middle. A powerful fan system consisting of one or multiple fans moves air past the object; the fan must have straightening vanes to smooth the airflow. The test object is instrumented with a sensitive balance to measure the forces generated by airflow; or, the airflow may have smoke other substances injected to make the flow lines around the object visible. Full-scale wind mill or vehicle or aircraft are sometimes tested in large wind tunnels, but these facilities are expensive to operate and some of their functions have been taken over by computer modelling. In addition to vehicles, wind tunnels are used to study the airflow around large structures such as bridges or office buildings. The earliest enclosed wind tunnels were invented in 1871; large wind tunnels were built during the Second World War. Wind tunnels were first proposed as a means of studying vehicles in free flight. The wind tunnel was envisioned as a means of reversing the usual paradigm: instead of the air's standing still and the vehicle or aircraft moving at speed through it, the same effect would be obtained if the vehicle or aircraft stood still and the air moved at speed past it. In that way a stationary observer could study the vehicle or aircraft in action, and could measure the aerodynamic forces being imposed on the aircraft. Wind-tunnel testing can be applied to automobiles to determine ways to reduce the power required to move the vehicle on roadways at a given speed. In these studies, the interaction between the road and the vehicle plays a significant role, and this interaction must be taken into consideration when

interpreting the test results. Some automotive test wind tunnels have incorporated moving belts under the test vehicle in an effort to approximate the actual condition. Low speed wind tunnels [1],[2] and wind tunnels for constructions industry [3],[4] has been studied by some the researchers. Wind tunnels for wind turbine testing [5], [6] and mechanical aspects [7] are very important. Instrumentation related aspects were found in some research papers [8]. Wind tunnel development is considered as mechanical engineering domain. However, many issues such as exhaust fan selection, anemometer selection and their placement involves electrical and instrumentation engineering. This paper has been organized to cover up various applications, measurement aspects and wind tunnels in India have been covered sequentially. Some scientists have done researches on low and medium speed turbine. Also few scholars use induction motor for wind power generation [9]-[13].

II. BASICS OF WIND TUNNEL

Just as the name suggests, a wind tunnel is a tube or tunnel that has man-made windblown through it at a certain speed. Engineers and Scientists put a model of an airplane, automobile or wind mill in the tunnel and then study the way air moves around the model. By looking at the way this smaller model acts in the wind tunnel, they get pretty good idea of how a real life-sized system of the same designs will probably behave. Wind tunnels work on the idea that a stationary model with air moving around it behaves the same way a actual, full-scale object under test moving through stationary air does. The models, usually made out of steel or aluminium, that are tested are loaded

with many instruments and sensors that report back to the computers in the control room. Air is blown or sucked through a duct equipped with a viewing port and instrumentation where models or geometrical shapes are mounted for study. Typically the air is moved through the tunnel using a series of fans. For very large wind tunnels several meters in diameter, a single large fan is not practical, and so instead, an array of multiple fans are used in parallel to provide sufficient airflow. Due to the sheer volume and speed of air movement required, the fans may be powered by stationary turbofan engines rather than electric motors. The air flow created by the fans that is entering the tunnel is itself highly turbulent in nature due to the fan blade motion and so it is not directly useful for accurate measurements. In large wind tunnels due to the effects of viscosity, the cross-section of a wind tunnel is typically circular rather than square. In the corners of a square tunnel air flow can be turbulent in nature. A circular tunnel provides a smoother flow than square tunnel. The lighting is usually embedded into the circular walls of the tunnel. Any lamp fitting on walls of wind tunnel disturbs the air flow pattern. Similarly, observation is usually done through transparent portholes into the tunnel. Lighting and observation windows are curved to match the cross-section of the tunnel and further reduce turbulence around the window. Various techniques are used to study the actual airflow around the geometry and compare it with theoretical results, which must also take into account the Reynolds number and Mach number for the regime of operation.

III. CLASSIFICATION OF WIND TUNNEL

Various types of wind tunnels are used in aerodynamic studies. Typically, wind tunnels are of classified on the basis of air circuit - The air circuit can be either closed circuit and open circuit. In an open circuit wind tunnel, the air is taken from outside environment and discharged to outside environment again. The air generally follows a straight path from the entrance to the exit of the wind tunnel. In closed circuit wind tunnels, the air is circulated by the help of a power unit continuously. Sometimes, a small amount of air is exchanged with the environment to increase the air quality and have some temperature control. Open circuit and closed circuit wind tunnels have some major advantages and disadvantages. Hence, the comparison of these two is presented in Table 1.

Table 1 Comparison of closed circuit and open circuit wind tunnels

Closed circuit wind tunnels	Open circuit wind tunnels
The quality of the flow can be well controlled and independent of atmosphere	Flow quality is easily affected from wind or room size
More construction cost and hence initial investment is higher	Less construction cost
The tunnel requires less energy (for a given size and speed)	The tunnel requires more energy (for a given size and speed)
Precautions must be taken if used for flow visualization	No purging problem in flow visualization
Less noisy Needs cooling if used extensively	The open circuit tunnels are more noisy

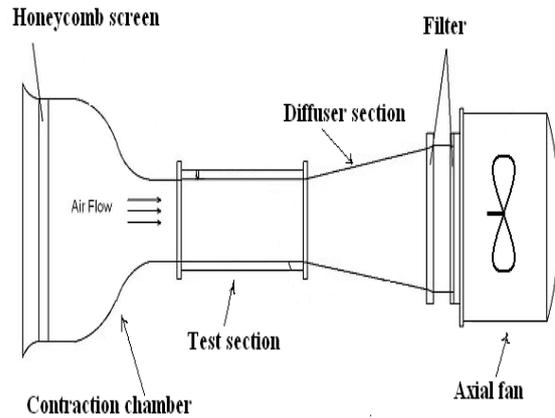


Fig 1 Open circuit wind tunnel

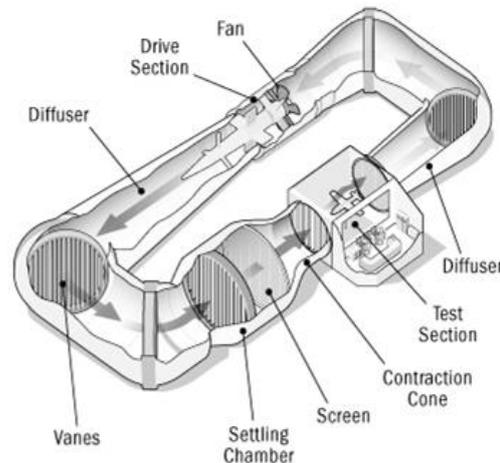


Fig 2 Closed circuit wind tunnel

Apart from this basic classification, wind tunnels can be classified as,

- Based on structure- funnel shaped or normal type, horizontal or vertical axis wind tunnel, long, short or medium length wind tunnel
- Based on structure material - Metallic structure or concrete type or composite structure wind tunnel
- Based on shape of inlet section - Semicircular, circular, square, semi- elliptical or other cross sections of various shapes
- Based on location- outdoor location or indoor location wind tunnel
- Based on speed of air velocity -low speed, medium speed, high speed. There are many different kinds of wind tunnels e.g. low-speed wind tunnel, high-speed wind tunnel, supersonic wind tunnel, subsonic wind tunnel
- Based on anemometer placement - push in type, windows for anemometer, anemometer frame type.

IV. ELECTRICAL ISSUES RELATED TO WIND TUNNEL.

Wind tunnel design and development involves mechanical engineering and civil engineering. However, some of the factors such as exhaust fans, anemometer, lighting arrangement and provision of electrical supply involves electrical supply involves electrical and instrumentation engineering. Following subsections are dealing with some of these aspects,

A. Exhaust Fans

Exhaust fans can be fitted at inlet or outlet of wind tunnel. It can push the air in test chamber or suck the air from the test chamber. These fans are induction motor based which can be three phase or single phase induction motors. Number of fans required for the wind tunnel is decided by various factors such as area of wind tunnel for passage of air, required speed range of air, diameter of each fan and air delivery required. Speed of fan, number of blades for fan, type of blade used decides the air delivery of fans system used in wind tunnel. Usually high capacity, heavy duty fans are selected for wind tunnels as volume of air circulated and the speed at which it is done is high. Air delivery in cubic meter per second and total area through which air is to be passed decides the number of fans required. Following equation is suitable for estimating number of fans required

$$n = A \cdot V / ad$$

Where

n- Number of fans to be used

A- Area of wind tunnel through which air passes in square meter

V- Velocity of air required in wind tunnel in meter per second

ad- Air delivery of exhaust fans in cubic meter per second

To generate various aerodynamic conditions, fan speed is required to be changed. For multiple exhaust fans, each fan requires separate speed regulator. Simplest arrangement can be autotransformer controller which is based on speed control by voltage control method. Low power factor is the major drawback of this controller. Now days, triac based controllers are preferred due to its size, cost, weight and control convenience. However, this type of controller which is based on high speed switching creates problems of harmonic distortions.

B. Anemometer

Anemometer is used to measure speed of air. Anemometer can be of following types,

1. Cup type of anemometers – It is also known as rotational anemometers, cup anemometers are the simplest types of anemometers and have been around for a very long time. The construction of these meters consists of a vertical central pole and four horizontal arms at the top that have a cup attached to each of them. As wind presses against these cups, the arms at the top rotate around the central pole. The speed of the rotation would determine the speed of the wind. The speed of the wind is usually observed through digital readouts in these anemometers. Researchers, meteorologists and many educational institutions worldwide make use of these anemometers for commercial or research activities. Not only for commercial, but one can make their own anemometer for their own personal use. For these meters, the speed of the wind can be calculated by multiplying the revolutions the cups make in a minute with the circumference that the cups create. This method would provide a rough estimate of the speed of the wind. A disadvantage of these meters is that they are prone to friction. As the cups rotate around their axis,

they encounter friction which could affect the accuracy of the readings.

2. Propeller type of anemometers - These anemometers, just like the cup anemometers, measures the velocity of the wind. They are also able to determine the direction of the wind as they have a propeller that is attached to the front of the device with a tail section behind, on the same axis as the propeller on a central pole. As wind presses against the propeller, it spins it and the faster the propeller spins, the faster is the velocity of the windmill anemometer. The windmill anemometer adopts that shape of a windmill, hence its name. The windmill anemometer has to be parallel to the direction of the wind in order for it to function properly and provide accurate results. The turning effect of the propeller causes the mechanism in the anemometer to be able to calculate the speed of the wind.
3. Ultrasonic anemometer - Ultrasonic, as its name would suggest, involves sonic pulses to measure the velocity of the wind. The device sends sonic pulses across a path to sensors located across which are able to sense the incoming pulses. As the movement of wind is able to disrupt sonic pulses, the disruption is used to determine the speed of the wind. These anemometers are able to provide very accurate measurements of wind data. They also do not involve any moving parts and thus are able to detect very minimal changes in the speed of the wind. They usually make use of four sensors that are arranged in a square pattern to be able to get accurate results.

Placement of anemometers should be just touching the inner wall of tunnel so as to avoid the disturbance to air flow. Sometimes, multiple anemometers are required in tunnel to carry out specific aerodynamic studies. In such case, a special structure is placed in wind tunnel which can hold various anemometers at desired location in wind tunnel. For transient studies, anemometers are directly connected to computer system.

C. Lighting arrangement

Typical wind tunnel has lights in it. Lamp fittings are embedded in to the inner wall of the wind tunnel. Thus, there is no disturbance to the air flow. LED lamp arrangement is most suitable for the wind tunnels as it can be placed along with the wall without affecting the air flow pattern.

V. MEASUREMENT OF PARAMETERS IN WIND TUNNELS

Air velocity and pressures are measured in several ways in wind tunnels. Air velocity through the test section can be determined by Bernoulli's principle. The direction of airflow around a model can be determined by tufts of yarn attached to the aerodynamic surfaces. The direction of airflow approaching a surface can be visualized by mounting threads in the airflow. Bubbles or smoke of liquid can be introduced into the airflow upstream of the test model, and their path around the model can be photographed. Beam balance is used to measure aerodynamic forces on the test model. The pressure

distributions across the test model have historically been measured by drilling many small holes along the airflow path, and using multi-tube manometers to measure the pressure at each hole. Pressure distributions can more conveniently be measured by the use of pressure-sensitive paint, in which higher local pressure is indicated by lowered fluorescence of the paint at that point. Pressure distributions can also be conveniently measured by the use of pressure-sensitive pressure belts, in which multiple ultra-miniaturized pressure sensor modules are integrated into a flexible strip.

The strip is attached to the aerodynamic surface with tape, and it sends signals showing the pressure distribution along its surface. Pressure distributions on a test model can also be determined by performing a wake survey, in which either a single pitot tube is used to obtain multiple readings downstream of the test model, or a multiple-tube manometer is mounted downstream and all its readings are taken. Many a times, all measurements of wind tunnel parameters are passed on to computers through digital instrumentation.

VI. CONCLUSIONS

There are very few wind tunnels even in some developed countries. By and large, they are of smaller/medium size and hence not suitable for automobile /energy sector trials i.e. automobiles aerodynamic studies and wind energy related testing. This is the main hurdle in research and development of these sectors. Research in this area cannot be done at college level as such facilities are not available with educational institutes. UG/PG level projects in this area cannot be taken by students. Thus entire research work in these areas is done by the industry. If more wind tunnels of medium and high capacity are constructed at university and college levels then young engineers can work on some innovative areas such as development of low speed wind turbines, efficiency improvement of vehicle by modifying its shape etc.

Wind tunnels and test models aren't cheap to build. That's why more and more organizations are deactivating their wind tunnels and shifting to computer modelling, which is now often used in place of physical models and tunnels. What's more, computers let engineers adjust infinite variables of the model and the test section without time consuming manual labour. However, physical tunnels are used to retest the results of computer modelling. Such retesting is essential in many fields and hence wind tunnels have got its own importance. Thus this paper has presented the classification and basics of wind tunnel. Need of wind tunnel, its construction, applications and associated parameters have been presented.

Measurement and control aspects of wind tunnel have been presented in this paper. Exhaust fan speed control, air flow measurement are critical systems in wind tunnel design. It is well known that lack of this facility is the main hurdle in research and development activities in wind energy sector.

REFERENCES

- [1] Moller, T.J.; Ortmanns, J.; El Khalfaoui, M.; Radespiel, R., "The new low speed wind tunnel of the TU Braunschweig", 20th IEEE Instrumentation in Aerospace Simulation Facilities Congress, ICIASF '03, 2003, pp. 399 – 402.
- [2] Boyle, M. T., "Low speed wind tunnel testing", IEEE Semiconductor Thermal and Temperature Measurement Symposium, 1988. SEMI-THERM IV., 1988, pp. 31 – 39.
- [3] Jun Jiang ; Jiping Hao, , "Wind tunnel test study on rigid model of a super high-rise building", IEEE Remote Sensing, Environment and Transportation Engineering conf. RSETE 2011, pp.1884 – 1887.
- [4] Jun Gao ; Jianghai Geng ; Boyan Jia, "Research on Flashover Voltage of Composite Insulator with Wind Tunnel Test", IEEE Power and Energy Engineering Conf. (APPEEC), 2010 Asia-Pacific, 2010, pp. 1 – 4.
- [5] Meng-Tse Lee ; Hsueh-Liang Huang ; Chun-Mao Pai, "The development of a PSD-based precision measurement and control system for wind tunnel", IEEE Electronics, Communications and Control conf. (ICECC), 2011, pp. 4566 – 4570.
- [6] Yang Guangjun ; Bai Cunru ; Sun Jing, "Research on Vibration Source and Transfer Path for Power Section of Low Turbulence Wind Tunnel", IEEE Measuring Technology and Mechatronics Automation conf. ICMTMA, 2010 Vol.3, pp. 231 – 234.
- [7] Sikka, K.K. ; Fisher, Timothy S. ; Torrance, K.E. ; Lamb, C.R. , "Effects of wind tunnel orientation and mixed convection on heat transfer from a PQFP, IEEE Thermal Phenomena in Electronic Systems conf. 1996. I-THERM V., 1996, pp. 21 – 30.
- [8] Schimanski, D. , "Status of the development programme for instrumentation and test techniques of the European Transonic Wind Tunnel" IEEE Instrumentation in Aerospace Simulation Facilities congress 1989. ICIASF '89, pp. 450 – 459.
- [9] D. S. Chavan, S. D. Bhide, P. B. Karandikar , "Influence of horizontal wind shear on flicker emission severity in wind farm" 4th International Conference on Advances in Energy Research ICAER 2013, Indian Institute of technology, IIT, Mumbai, India (2013)
- [10] D.S.Chavan, S.D. Bhide, P.B. Karandikar, "Effect of vertical wind shear on flicker in wind farm" IEEE Global Humanitarian Technology Conference South Asia Satellite, GHTC SAS, Trivandrum, Kerala, India (2013).
- [11] D. S. Chavan, "Advanced instrumentation for collection of wind energy variables" National conference on alternative energy sources Sihagad Engineering Pune, India (2011)
- [12] D.S.Chavan, K. S. Patil, "Experimental set to test slip ring induction generator for wind energy generation" National Conference on Renewable Energy Commercialization Organized by PVG's College of Engineering & Technology, Pune, India (2012)
- [13] D.S.Chavan, K.S Patil, "Wind Power Generation Use of Slip Ring Induction Generator" International Journal of Recent Technology and Engineering Exploring Innovation,