ENGINE DESIGN AND OPERATING PARAMETERS

Nazaruddin Sinaga
Laboratorium Efisiensi dan Konservasi Energi
Universitas Diponegoro

IMPORTANT ENGINE CHARACTERISTICS

- In this chapter, some basic geometrical relationships and the parameters commonly used to characterize engine operation are developed.
- The factors important to an engine user are:

1. The engine's performance over its operating range
2. The engine's fuel consumption within this operating range and the cost of the required fuel
3. The engine's noise and air pollutant emissions within this operating range
4. The initial cost of the engine and its installation.

5. The reliability and durability of the engine, its maintenance requirements, and how these affect engine availability and operating costs

- These factors control total engine operating costs- usually the primary consideration of the user-and whether the engine in operation can satisfy environmental regulations.
- This course is concerned primarily with the performance, efficiency, and emissions characteristics of engines; the omission of the other factors listed above does not, in any way, reduce their great importance.

Engine performance is more precisely defined by:

1. The maximum power (or the maximum torque) available at each speed within the useful engine operating range
2. The range of speed and power over which engine operation is satisfactory

The following performance definitions are commonly used:

- **Maximum rated power**. The highest power an engine is allowed to develop for short periods of operation.
- **Normal rated power**. The highest power an engine is allowed to develop in continuous operation.
- **Rated speed**. The crankshaft rotational speed at which rated power is developed.

GEOMETRICAL PROPERTIES OF RECIPROCATING ENGINES

The following parameters define the basic geometry, of a reciprocating engine (see Fig. 2.1):

Compression ratio r_c :

$$r_c = \frac{\text{maximum cylinder volume}}{\text{minimum cylinder volume}} = \frac{V_d + V_c}{V_c} \tag{2.1}$$

where V_d, is the displaced or swept volume and V_c is the clearance volume.

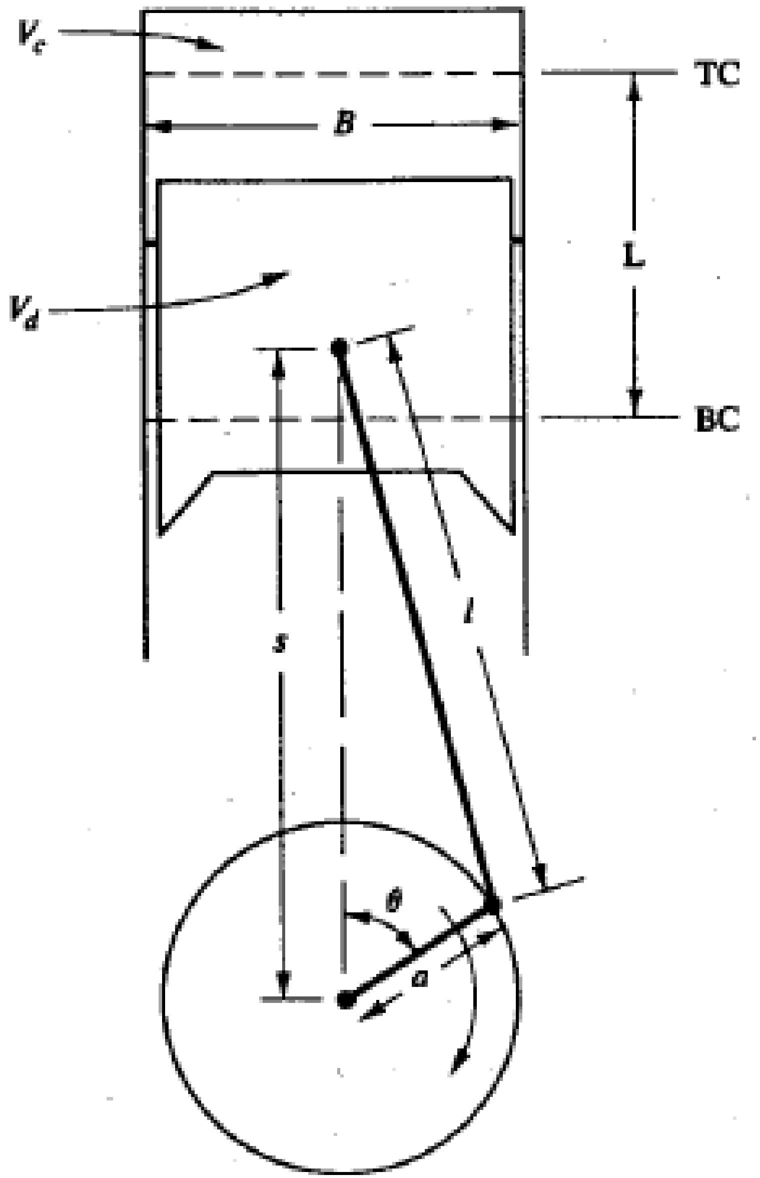


FIGURE 2-1
Geometry of cylinder, piston, connecting rod, and crankshaft where B = bore, L = stroke, l = connecting road length, a = crank radius, θ = crank angle.

- Ratio of cylinder bore to piston stroke:

$$R_{bs} = \frac{B}{L}$$

- Ratio of connecting rod length to crank radius:

$$R = \frac{l}{a}$$

- The stroke and crank radius are related by

$$L = 2a$$

- Typical values of these parameters are: r_c = 8 - 12 for SI engines and 12 - 24 for CI engines;
- B/L = 0.8 to 1.2 for small- and medium-size engines, decreasing to about 0.5 for large slow-speed CI engines;
- R = 3 - 4 for small-and medium-size engines, increasing to 5 - 9 for large slow-speed CI engines.

The cylinder volume V at any crank position θ is

$$V = V_c + \frac{\pi B^2}{4}(l + a - s)$$

where s is the distance between the crank axis and the piston pin axis (Fig. 2-I), and is given by

$$s = a\cos\theta + (l^2 - a^2\sin^2\theta)^{1/2}$$

The angle θ, defined as shown in Fig. 2-1, is called the ***crank angle***.

Equation (2.4) with the above definitions can be rearranged:

$$\frac{V}{V_c} = 1 + \tfrac{1}{2}(r_c - 1)[R + 1 - \cos\theta - (R^2 - \sin^2\theta)^{1/2}]$$

The combustion chamber surface area A at any crank position θ is given by

$$A = A_{ch} + A_p + \pi B(l + a - s)$$

where A_{ch} is the cylinder head surface area and A_p is the piston crown surface area. For flat-topped pistons, $A_p = \pi B^2/4$.

Using Eq. (2.5), Eq. (2-7) can be rearranged

$$A = A_{ch} + A_p + \frac{\pi BL}{2}\left[R + 1 - \cos\theta - (R^2 - \sin^2\theta)^{1/2}\right]$$

An important characteristic speed is the mean piston speed S_p :

$$\bar{S}_p = 2LN$$

where N is the rotational speed of the crankshaft.

- Mean piston speed is often a more appropriate parameter than crank rotational speed for correlating engine behavior as a function of speed.
- For example, gas-flow velocities in the intake and the cylinder all scale with S_p. The instantaneous piston velocity S_p, is obtained from

$$S_p = \frac{ds}{dt}$$

- The piston velocity is zero at the beginning of the stroke, reaches a maximum near the middle of the stroke, and decreases to zero at the end of the stroke.
- Differentiation of Eq. (2.5) and substitution gives

$$\frac{S_p}{\bar{S}_p} = \frac{\pi}{2} \sin\theta \left[1 + \frac{\cos\theta}{(R^2 - \sin^2\theta)^{1/2}}\right]$$

- Figure 2-2 shows how S, varies over each stroke for R = 3.5

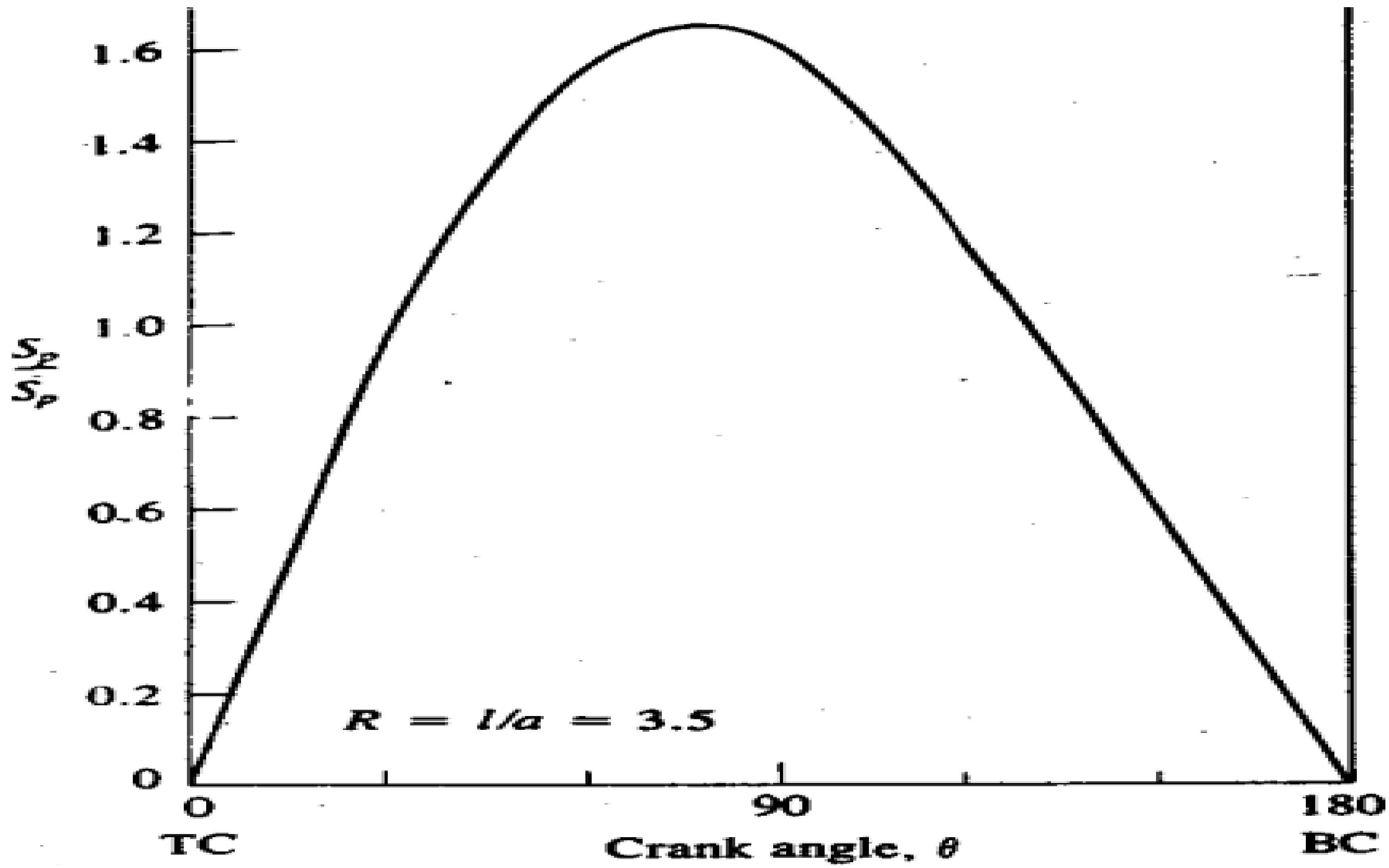


FIGURE 2-2 Instantaneous piston speed/mean piston speed as a function of crank angle for R = 3.5.

- Resistance to gas flow into the engine or stresses due to the inertia of the moving parts limit the maximum mean piston speed to within the range 8 to 15 m/s (1500 to 3000 ft/min).

- Automobile engines operate at the higher end of this range; the lower end is typical of large marine diesel engines.

2.3 BRAKE POWER AND TORQUE

- Engine torque is normally measured with a dynamometer.
- The engine is clamped on a test bed and the shaft is connected to the dynamometer rotor.
- Figure 2-3 illustrates the operating principle of a dynamometer.

  The rotor is coupled electromagnetically, hydraulically, or by mechanical friction to a stator, which is supported in low friction bearings.

  The stator is balanced with the rotor stationary.

  The torque exerted on the stator with the rotor turning is measured by balancing the stator with weights, springs, or pneumatic means.

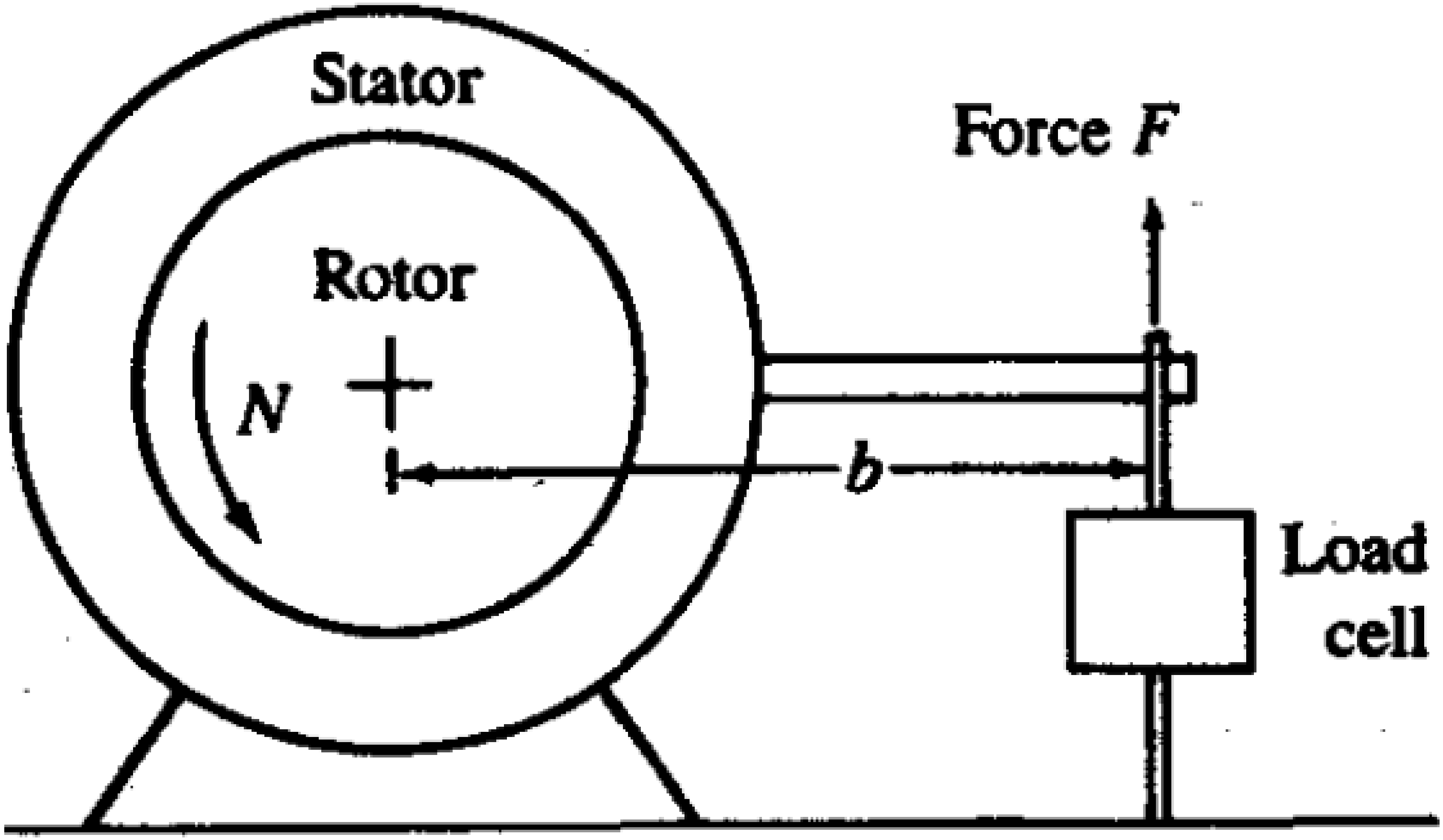
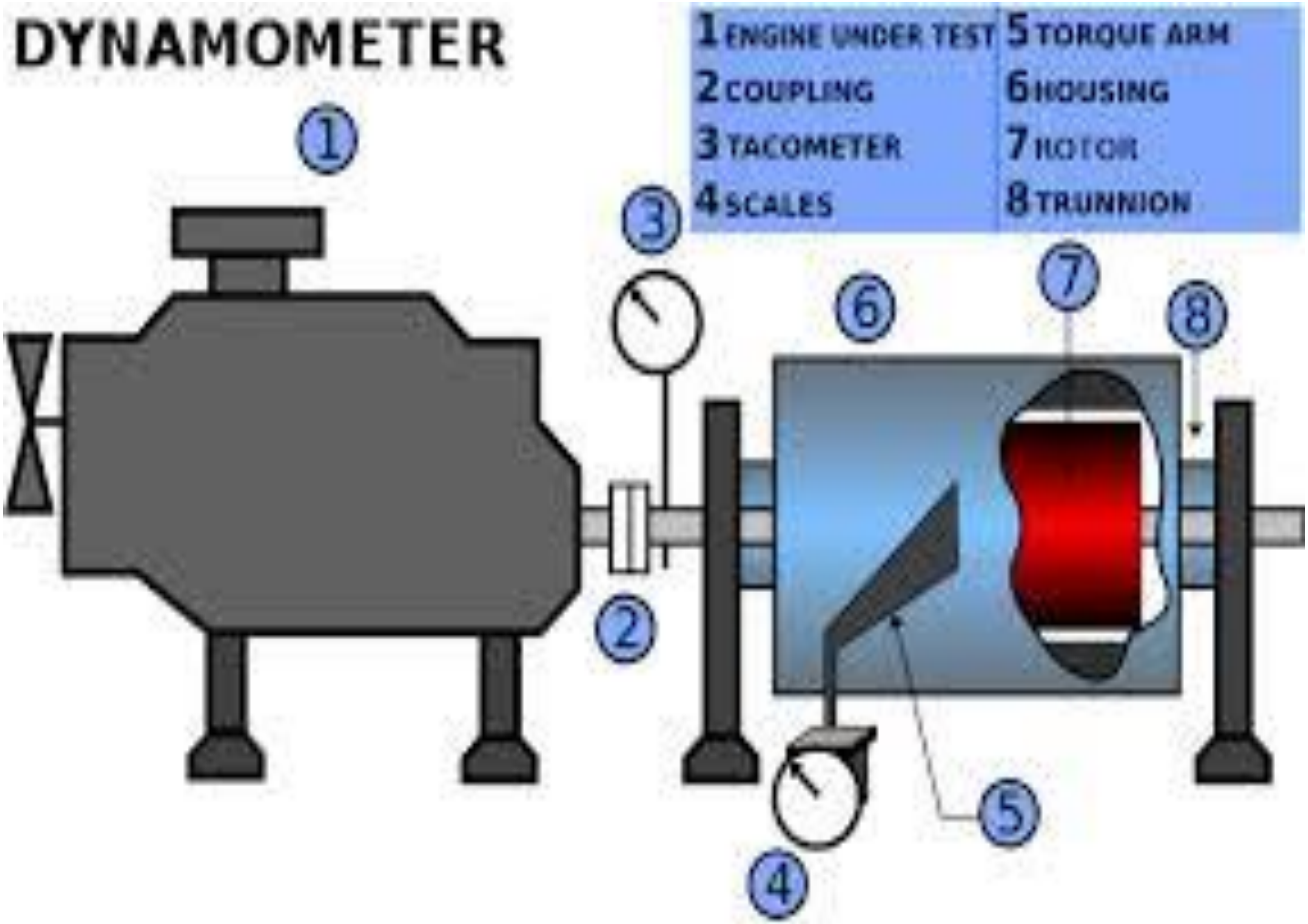
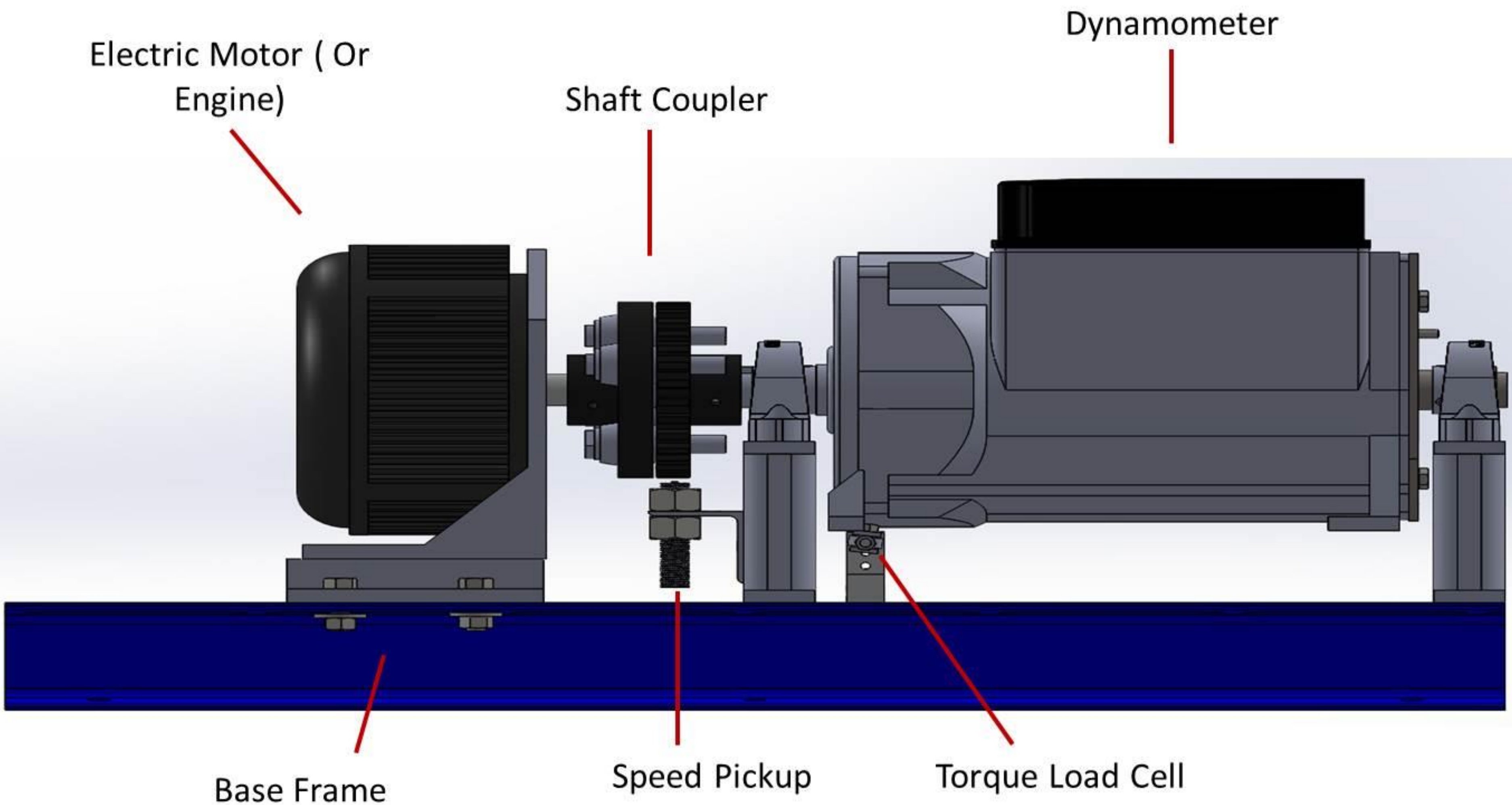


FIGURE 2-3 Schematic of principle of operation of dynamometer

DYNAMOMETER




Electric Motor (Or Engine)
Shaft Coupler
Dynamometer
Base Frame
Speed Pickup
Torque Load Cell

Using the notation in Fig. 2-3, if the torque exerted by the engine is T:

$$T = Fb \tag{2.12}$$

The power P delivered by the engine and absorbed by the dynamometer is the product of torque and angular speed:

$$P = 2\pi NT \tag{2.13a}$$

where N is the crankshaft rotational speed. In SI units:

$$P(\text{kW}) = 2\pi N(\text{rev/s})T(\text{N}\cdot\text{m}) \times 10^{-3} \tag{2.13b}$$

or in U.S. units:

$$P(\text{hp}) = \frac{N(\text{rev/min})\ T(\text{lbf}\cdot\text{ft})}{5252} \tag{2.13c}$$

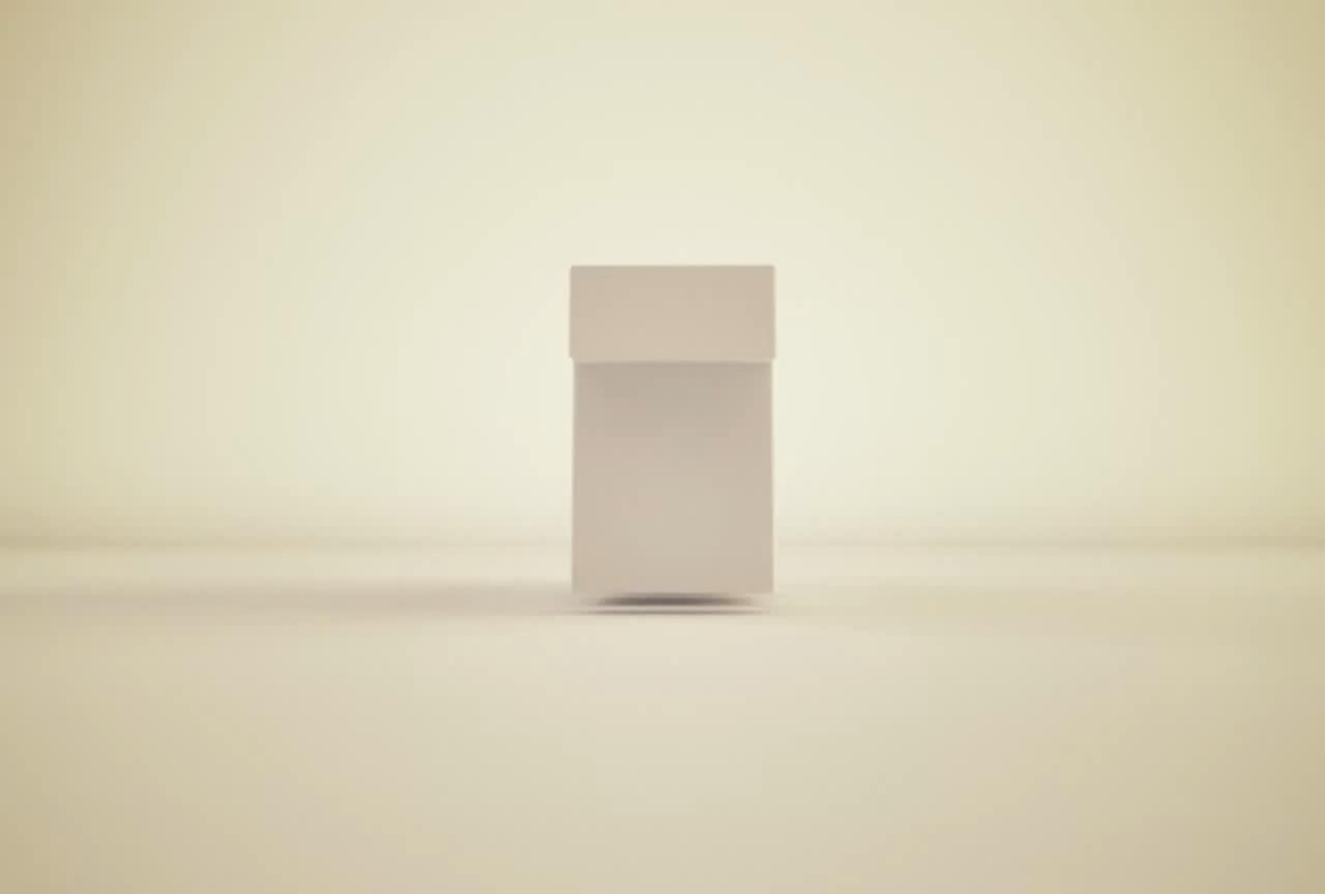
- Note that torque is a measure of an engine's ability to do work; power is the rate at which work is done.

- The value of engine power measured as described above is called brake power P_b.

- This power is the usable power delivered by the engine to the load-in this case, a "brake."


WARNING


MD HD



THANK YOU

REFERENCES

1. **Heywood, J.** *Internal Combustion Engine Fundamentals*, McGraw-Hill, New York, 1988.
2. **Pulkrabek, W.C.** *Engineering Fundamentals of the Internal Combustion Engine*, Prentice Hall, Upper Saddle River, New Jersey, 2003.
3. **Colin R. Ferguson and Allan T. Kirkpatrick**. *Internal Combustion Engines: Applied Thermal Sciences*, 2nd Edition,, John Wiley and Sons, New York, 2000.
4. **Gupta, H.** N. *Fundamentals of Internal Combustion Engines*, PHI Learning Private Limited, New Delhi, 2009.
5. **Awaludin, W. Panuntun, W.S. Alam, N. Sinaga**. *Pemilihan Mesin Penggerak Generator Pada Sistem Pembangkit Listrik Tenaga Biogas (PLTBG)*, Seminar Nasional Teknik Kimia, Jurusan Teknik Kimia FT Undip, 2003.
6. **Sinaga, Nazaruddin, R. Ismail, R. Perangin-angin dan O. A. Wicaksono**. *Pembangkitan Listrik Menggunakan Bahan Bakar Biogas dari Hasil Fermentasi Kotoran Ternak*, Seminar Nasional Teknik Kimia, Jurusan Teknik Kimia FT Undip, 2003.
7. **Sinaga, Nazaruddin**. *Perancangan Mixer Biogas-Udara Untuk Mesin Diesel Dual Fuel Pembangkit Listrik Tenaga Biogas*, Majalah Teknik, Tahun ke XXV, Edisi I, 2005.
8. **Sinaga, Nazaruddin**. *Analisa dan Pemilihan Mesin Untuk Mesin Dual Fuel Campuran Biogas-Solar*, Majalah Rotasi, Jurusan Teknik Mesin FT Undip, Vol. 7 No. 2, April, 2005.
9. **Sinaga, Nazaruddin**. *Perancangan Conversion Kit Untuk Modifikasi Mesin Diesel Dual Fuel Pembangkit Listrik Tenaga Biogas*, Jurnal Ilmiah Nasional Efisiensi dan Konservasi Energi, Jurusan Teknik Mesin, FT Undip, Vol. 1 No. 1, September, 2005.
10. **Cahyono, Sukmaji Indro, Gwang-Hwan Choe, and Nazaruddin Sinaga**. *Numerical Analysis Dynamometer (Water Brake) Using Computational Fluid Dynamic Software*. Proceedings of the Korean Solar Energy Society Conference, 2009.
11. **Priangkoso, Tabah dan N. Sinaga**. *Tinjauan Beberapa Model Mekanistik Tingkat Konsumsi Bahan Bakar Untuk Diterapkan Pada Program Simulator Mengemudi Hemat Energi Smart Driving*,

Prosiding, Seminar Nasional Sains dan Teknologi ke-2, Fakultas Teknik Universitas Wahid Hasyim Semarang, Juni 2011.

12. **Mrihardjono, Juli dan N. Sinaga**. *Pengujian Model Driving Cycle Kendaraan Honda City Berbahan Bakar Premium*, Majalah Gema Teknologi, Volume 16, Nomor 3, April - Oktober 2011, ISSN : 0852 0232.
13. **Sinaga, Nazaruddin dan Tabah Priangkoso**. *Tinjauan/Review Model Empirik Konsumsi Bahan Bakar Kendaraan*, Journal Momentum, Vol. 7, No. 1, April 2011.
14. **Supriyo dan N. Sinaga**. *Perencanaan Daya Pendingin pada Dinamometer Arus Eddy,* Eksergi, Jurnal Teknik Eergi POLINES, Volume 7, Nomor 3, ISSN : 0216-8685, September 2011.
15. **Supriyo dan N. Sinaga**. *Perancangan Dinamometer Arus Eddy Kapasitas 250 KW*, Majalah Eksergi, Volume 7, Nomor 3, ISSN : 0216-8685, September 2011.
16. **Sinaga, Nazaruddin**. *Pengujian Teknik Mengemudi Hemat Energi pada Kendaraan Penumpang untuk Mendukung Program Smart Driving di Indonesia*, Prosiding, Seminar Nasional Teknik Mesin X (SNTTM X), Jurusan Teknik Mesin, Fakultas Teknik Universitas Brawijaya, Malang, November 2011.
17. **Sinaga, Nazaruddin, T. Priangkoso, D. Widayana dan K. Abdurrohman**. *Kaji Eksperimental Pengaruh Beberapa Parameter Berkendaraan Terhadap Tingkat Konsumsi Bahan Bakar Kendaraan Penumpang Kapasitas Silinder 1500-2000cc*, Prosiding, Seminar Nasional Teknik Mesin X (SNTTM X), Jurusan Teknik Mesin, Fakultas Teknik Universitas Brawijaya, Malang, November 2011.
18. **Sinaga, Nazaruddin dan B. Prasetiyo**. *Kaji Eksperimental Karakteristik Sebuah Dinamometer Sasis Arus Eddy*, Eksergi, Jurnal Teknik Energi POLINES, Volume 8, Nomor 2, Mei 2012, ISSN : 0216-8685.
19. **Sinaga, Nazaruddin dan A. Dewangga**. *Pengujian Dan Pembuatan Buku Petunjuk Operasi Chassis Dinamometer Tipe Water Brake*, Majalah Rotasi, Volume 14, Nomor 3, Juli 2012, ISSN:1411-027X.
20. **Sinaga, Nazaruddin**. *Smart Driving : Menghemat Bahan Bakar, Meningkatkan Kualitas Emisi Dan Menurunkan Resiko Kecelakaan,* Makalah, Seminar Astra – Jurusan Teknik Mesin Undip, Jurusan Teknik Mesin FT UNDIP, November 2012.
21. **Sinaga, Nazaruddin dan Mulyono**. *Kaji Eksperimental Dampak Pemakaian Pertamax Dan Pertamax-Plus Terhadap Emisi Gas Buang*

Pada Sepeda Motor, Prosiding, Seminar Nasional Unit Penelitian dan Pengabdian Kepada Masyarakat Politeknik Negeri Semarang 2013, ISBN : 978-979-3514-66-6, Halaman 168-172.

22. **Sinaga, Nazaruddin, dan M. H. Sonda**. *Pemilihan Kawat Enamel Untuk Pembuatan Selenoid Dinamometer Arus Eddy Dengan Torsi Maksimum 496 Nm*, Eksergi, Jurnal Teknik Energi Vol 9 No.1 Januari 2013.
23. **Sinaga, Nazaruddin dan S. J. Purnomo**. *Hubungan Antara Posisi Throttle, Putaran Mesin dan Posisi Gigi Terhadap Konsumsi Bahan Bakar pada Beberapa Kendaraan Penumpang*, Eksergi, Jurnal Teknik Energi, Vol.9 No. 1, Januari 2013.
24. **Sinaga, Nazaruddin**. Pelatihan Teknik Mengemudi Smart Driving Untuk Menurunkan Emisi Gas Rumah Kaca Dan Menekan Biaya Transportasi Angkutan Darat, Prosiding, Seminar Nasional Teknik Mesin XII (SNTTM XII), Fakultas Teknik Universitas Lampung, Oktober 2013.
25. **Sinaga, Nazaruddin, S. J. Purnomo dan A. Dewangga**. *Pengembangan Model Persamaan Konsumsi Bahan Bakar Efisien Untuk Mobil Penumpang Berbahan Bakar Bensin Sistem Injeksi Elektronik (EFI)*, Prosiding, Seminar Nasional Teknik Mesin XII (SNTTM XII), Fakultas Teknik Universitas Lampung, Oktober 2013.
26. **Sinaga, Nazaruddin dan Y.N. Rohmat**. *Perbandingan Kinerja Sepeda Motor Berbahan Bakar Lpg Dan Bensin, Prosiding, Seminar Nasional Teknologi Industri Hijau*, Semarang 21 Mei 2014, Balai Besar Teknologi Pencegahan Pencemaran Industri (BBTPPI) Semarang, BPKIMI, Kementrian Perindustrian, Mei 2014.
27. **Syachrullah, L.I, dan N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network (ANN)*, Prosiding, Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke-2, Fakultas Teknik Universitas Gajah Mada Yogyakarta, Juni 2014.
28. **Paridawati dan N. Sinaga**. *Penurunan Konsumsi Bahan Bakar Sepeda Motor Sistem Injeksi Menggunakan Metode Optimasi Artificial Neural Network Dengan Algoritma Back-Propagation*, Prosiding, Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke-2, Fakultas Teknik Universitas Gajah Mada Yogyakarta, Juni 2014.
29. **M. Rifal dan N. Sinaga**. *Impact of Methanol-Gasoline Fuel Blend on The Fuel Consumption and Exhaust Emission of an SI Engine*,

Proceeding, The 3rd International Conference on Advanced Materials Science and Technology (ICAMST 2015), Universitas Negeri Semarang, April 2015.

30. **Sinaga, Nazaruddin dan Mulyono**. *Studi Eksperimental Karateristik Kinerja Sepeda Motor Dengan Variasi Jenis Bahan Bakar Bensin*, Majalah Eksergi, Volume 11, Nomor 1, ISSN:0216-8685, Halaman 1-6 Januari 2015.

31. **Syahrullah, L. I. dan N. Sinaga**. *Optimization and Prediction of Motorcycle Injection System Performance with Feed-Forward Back-Propagation Method Artificial Neural Network (ANN),* American Journal of Engineering and Applied Sciences, Volume 9, Issue 2, ISSN: 1941-7039, Halaman 222-235, Februari 2016.

32. **Rojak, Amirur dan N. Sinaga**. *Pengaruh Penggunaan Bahan Bakar LGV Pada Mobil Penumpang 1200 CC Dan 1500 CC Terhadap Kebutuhan Udara Dan Bahan Bakar*, Politeknosains, Volume XV, Nomor 1, ISSN: 1829-6181, Maret 2016.

33. **Khudhoibi dan N. Sinaga**. *Pengaruh Engine Remap Terhadap Beberapa Parameter Operasi Mobil Berbahan Bakar LGV*, Jurnal Ilmiah Momentum, Volume 12, Nomor 1, ISSN : 0216-7395, April 2016.

34. **Rifal, Mohamad dan N. Sinaga**. *Impact of Methanol-Gasoline Fuel Blend on The Fuel Consumption and Exhaust Emission of an SI Engine*, AIP Conf. Proc. 1725, 020070-1–020070-6; Published by AIP Publishing, 978-0-7354-1372-6, Maret 2016.

35. **Sinaga, Nazaruddin dan D. Alcita**. *Perbandingan Beberapa Parameter Operasi Mesin Mobil Injeksi Terhadap Penggunaan Bahan Bakar Bensin dan Campuran Metanol-Bensin M15*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 12 No. 3, September 2016.

36. **Nazaruddin Sinaga**. *Perancangan Awal Conventer Kit LPG Sederhana untuk Konversi Mesin Bensin Skala Kecil*, Eksergi, Jurnal Teknik Energi POLINES, Vol. 13, No. 1, Januari 2017.

37. **Nazaruddin Sinaga**. *Kaji Numerik Aliran Jet-Swirling Pada Saluran Annulus Menggunakan Metode Volume Hingga*, Jurnal Rotasi Vol. 19, No. 2, April 2017.

38. **Nazaruddin Sinaga dan M. Rifal**. *Pengaruh Komposisi Bahan Bakar Metanol-Bensin Terhadap Torsi Dan Daya Sebuah Mobil Penumpang Sistem Injeksi Elektronik 1200 CC*, Jurnal Rotasi Vol. 19, No. 3, Juli 2017.

39. **Nazaruddin Sinaga.** *Perancangan dan Pembuatan Data Logger Sederhana untuk Dinamometer Sasis Sepeda Motor*, Jurnal Rotasi, Vol. 20, No. 1, Januari 2018.
40. **Mohamad Rifal dan Nazarudin Sinaga**. *Kaji Eksperimental Rasio Metanol-Bensin Terhadap Konsumsi Bahan Bakar, Emisi Gas Buang, Torsi Dan Daya*, Gorontalo Journal of Infrastructure and Science Engineering, Vol 1 (1), April 2018, pp. 47-54.
41. **Nugroho, A., Sinaga, N., Haryanto, I**. *Performance of a Compression Ignition Engine Four Strokes Four Cylinders on Dual Fuel (Diesel-LPG)*, Proceeding, The 17th International Conference on Ion Sources, Vol. 2014, 2018, 21 September 2018, AIP Publishing.
42. **Nazaruddin Sinaga, B. Yunianto, Syaiful, W.H. Mitra Kusuma**. *Effect of Addition of 1,2 Propylene Glycol Composition on Power and Torque of an EFI Passenger Car Fueled with Methanol-Gasoline M15*, Proceeding of International Conference on Advance of Mechanical Engineering Research and Application (ICOMERA 2018), Malang, October 2018.
43. **Nazaruddin Sinaga, Syaiful, B. Yunianto, M. Rifal**. Experimental and Computational Study on Heat Transfer of a 150 KW Air *Cooled Eddy Current Dynamometer*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
44. **Nazaruddin Sinaga**. *CFD Simulation of the Width and Angle of the Rotor Blade on the Air Flow Rate of a 350 kW Air-Cooled Eddy Current Dynamometer*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
45. **Ahmad Faoji, Syaiful Laila, Nazaruddin Sinaga**. *Consumption and Smoke Emission of Direct Injection Diesel Engine Fueled by Diesel and Jatropha Oil Blends with Cold EGR System*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
46. **Johan Firmansyah, Syaiful Laila, Nazaruddin Sinaga**. *Effect of Water Content in Methanol on the Performance and Smoke Emissions of Direct Injection Diesel Engines Fueled by Diesel Fuel and Jatropha Oil Blends with EGR System*, Proc. The 2019 Conference on Fundamental and Applied Science for Advanced Technology (Confast 2019), Yogyakarta, Januari 21, 2019.
47. **Sinaga, Nazaruddin, M. Mel, D.A Purba, Syaiful, and Paridawati**. *Comparative Study of the Performance and Economic Value of a Small*

Engine Fueled with B20 and B20-LPG as an Effort to Reduce the Operating Cost of Diesel Engines in Remote Areas, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.

48. **Sinaga, Nazaruddin, B. Yunianto, D.A Purba, Syaiful and A. Nugroho**. *Design and Manufacture of a Low-Cost Data Acquisition Based Measurement System for Dual Fuel Engine Researches*, Joint Conference of 6th Annual Conference on Industrial and System Engineering (6th International Conference of Risk Management as an Interdisciplinary Approach (1st ICRMIA) 2019 on April 23-24, 2019 in Semarang, Central Java, Indonesia.

49. **Y Prayogi, Syaiful**, **and N Sinaga**. *Performance and Exhaust Gas Emission of Gasoline Engine Fueled by Gasoline, Acetone and Wet Methanol Blends*, International Conference on Technology and Vocational Teacher (ICTVT-2018), IOP Conf. Series: Materials Science and Engineering 535 (2019) 012013 doi:10.1088/1757-899X/535/1/012013