⊙ 解　說

The survey on the technical trends of diesel engine digital governors and prospects of market in Korea

Y.H.YU　Korea Maritime University
J.S. Ha　Korea Maritime University

Abstract

In this paper the recent studies of digital governor for the Diesel Engine in Korea is summarized and that of usage in the marine and land field as of power plant is analyzed for the interest and development of the enterprise with relation to this industrial part.
Our investigation shows that until now the studies on the digital governor are mainly carried out in KMU and land usage for the power plants is increased gradually because reliance of digital governor is improved and system for the maneuvering and monitoring the plants is computerized.

1. Introduction.

There are various methods to increase the output power of marine propulsion Diesel Engine.
Those are increasing the sectional area of cylinder, the stroke of piston and mean effective pressure with high super charging and decreasing RPM of engine to increase the efficiency of propulsion etc.

Recent marine propulsion diesel engine tends to become slower in speed ,longer in stroke and higher in mean effective pressure to raise the output power per unit fuel by increasing the propulsion efficiency and decreasing the cooling loss and result in high output per cylinder.

Therefore the required numbers of cylinders to get the same output are decreased .

The marine propulsion diesel engine with long stroke, small numbers and large size of cylinders makes the uncontrollable time of fuel to be elongated with long explosion interval because the output power is not able to be controlled during explosion due to the fuel which had been already injected into cylinder previously even though the fuel rack is adjusted present time.
Due to this reason it is difficult for hydromechanical governor to prevent from over speed of engine with steep acceleration in case of sudden loss of load such as in rough sea condition and to prevent from hunting of rpm with jiggling of fuel rack in case of low load.

For example ,We assume that B&W 6L80MCE (of which MCR is 69.9 rpm) lost load suddenly , under assumptions of enough air supplied by super charger and the governor not to work, the percentage of engine acceleration rate per second is 89%/sec .Curve in Fig 1.1 explains how the acceleration is occurred in this case.

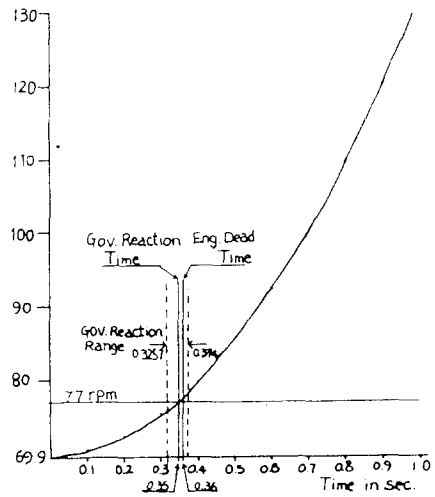
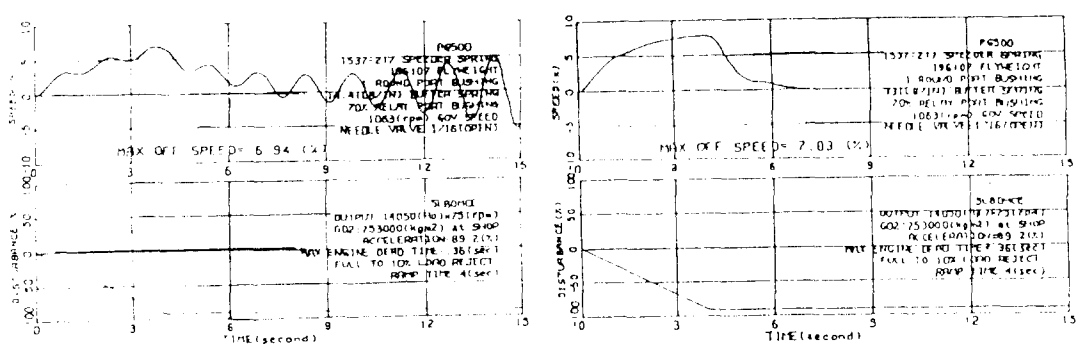


Fig 1.1 The Acceleration of engine when 100% load is off at MCR

Off speed of the hydromechanical governor is about 10.9%(or 77.5 rpm, 0.35 sec) on typical and also this type Governor can be adjusted within 9.5 - 12.5% by changing the buffer spring or relay valve of it. This is corresponding to 76.6 rpm(0.3257 sec) and 78.6 rpm(0.374 sec) but maker limitation is 10.3% (77 rpm) off speed.

The difference between governor response time and engine dead time, we call it as a governor reaction margin , is 0.01 sec which is far less than 0.2 sec in conventional case.

Fig 1.2(a) shows the response curves in the case of using 14.4 LB/in buffer spring and 70% relay port and 90% load off during 4 sec. We can see the engine is controlled under 6.94% off speed which is close to the over speed trip and is unstable after load being off.Fig 1.2 (b) explains the case of 33 LB/in buffer spring and different opening of needle valve but both case cannot be controlled within the allowable range.



(a) 14.4 LB/in buffer spring (b) 33 LB/in buffer spring

Fig 1.2 Response curve of engine when 90% load off in 4 sec

This is the reason why this engine maker recommend to use the digital governor when the parameter of multiplying number of cylinder by MCR(maximum continuous rpm) is less than 450 and to use it as possible when the parameter is between 450 and 700. Fig 1.3 shows this.

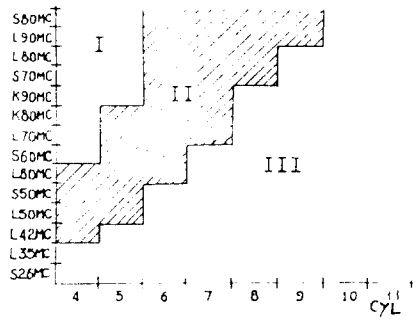


Fig 1.3 Recommanded range for usage of Digital Governor

2. Various studies on the digital governor in foreign countries

2.1 Studies on the small size and high speed diesel engine

Study of G.E. Harland and K.F.Gill

Harland and Gill studied on the David Brown Diesel Engine without supercharger of which power is 50 BHP and operating revolution is 1000 - 1400 rpm in 1973. They modeled combustion and revolution system of the diesel engine as first order system each as Fig. 2.1 and decided the rate of K1/K2 experimentally when the engine parameter was changed and proposed how to tune the parameter of PI controller to make the engine to be responded same as the model approximately with analog computer.

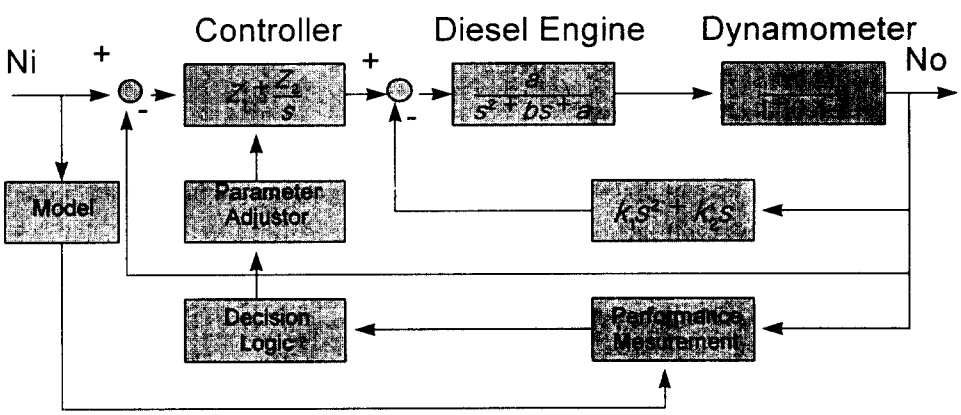


Fig. 2.1 Block Diagram of G.E. Harland and K.F.Gill Study

Study of P.E Wellstead, C.Thiruatooran, D.E. Winterbone

Wellstead et al studied on the 6 cyl. 4 stroke, medium speed (operating speed 1000 - 1800 rpm), turbo-charged 6YEX Ruston diesel engine. They divided the engine as High Speed High

Load(1800rmp, 810Nm), Mid Speed Mid Load(1400rpm,620Nm), Low Speed Low Load(1000rpm,210Nm) according to operating range and modeled it as Fig.2.2 in 1978.

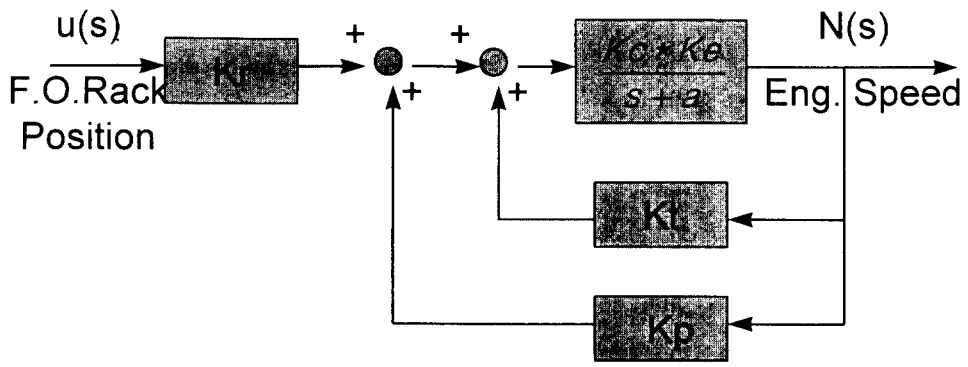


Fig.2.2 Block Diagram of P.E Wellstead, C.Thiruatooran, D.E. Winterbone study

They identified the parameters of transfer function with digital technique as following and knew that the identification was not accurate because mutual spectral of u(t) and r(t) was nearly zero with investigation of frequency response and that the pole of the engine transferred from the point near to positive origin when the operating range was in LSLL to the point near to negative origin when that range in HSHL. So they proposed gain Kt by turbocharger to be revised as to first order Kt/(s+b).

Study of P.A.Hazell and J.O.Flower

Hazell et al thought that diesel engine generated torque like square wave by the explosion of fuel and modeled it as discrete system and proposed P controller to control the speed of 6 cyl. 4 stroke 720 rpm 350 KW diesel engine.

Study of Y.Murayama, T.Terano, S.Masui, N.Akiyama

Murayama et al studied on the 3 cyl. 350 PS marine diesel engine and proposed fuzzy controller to minimize the fuel consumption with adjusting the fuel injection timing.

2.2 Studies on the large size and low speed diesel engine

Study of 北川正人

北川正人 studied on low speed diesel engine which was MCR 65 and 75 rpm , 2 stroke super charged marine diesel and modeled combustion system that the diesel engine generated torque as pulse wave by fuel combustion with constant time delay and the revolution system of first

order as in Fig 2.3. He seek for the dead time Tk and gain Ke with division of operating range as low speed , medium speed and high speed and simulated them by the computer with optimal PID parameter by critical sensitivity method with disregard of torque limit and surging limit.

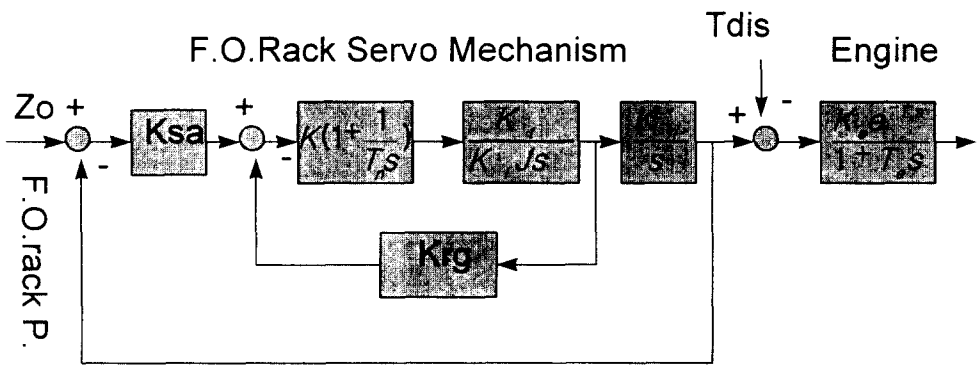


Fig. 2.3 Block Diagram of Gitagawa Study

Study of 佐藤勳

佐藤勳 developed MG-800 digital governor system with basis of the study of 北川正人 and experimented it with marine propulsion diesel engine MISTUI B&W 5S80MC and reported to have good results in 1987.

Study of 田村直樹

田村直樹 modeled the diesel engine as in Fig .2.4 and developed computer program to find changing trend of optimal parameters according to the criterion function to reduce the change of manipulation.

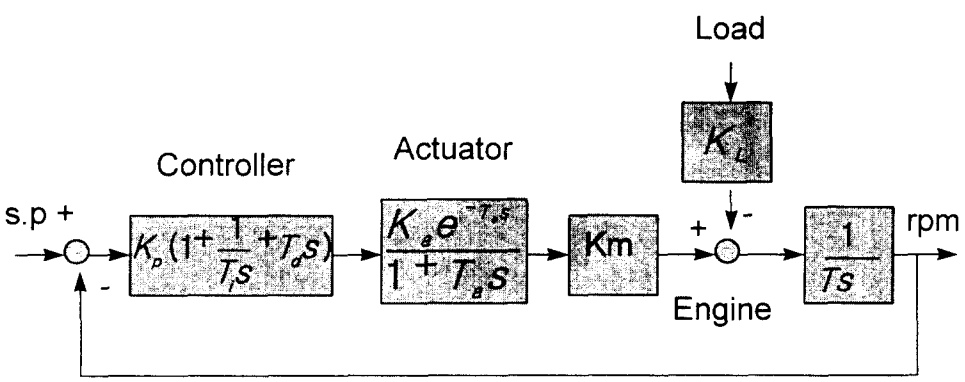


Fig. 2.4 Block Diagram of 田村直樹 Study

Study of Norcontrol company

They modeled low speed large diesel engine of which combustion system was a first order

system with dead time and revolution system also first order system as in Fig. 2.5 and manufactured DGS8800 system

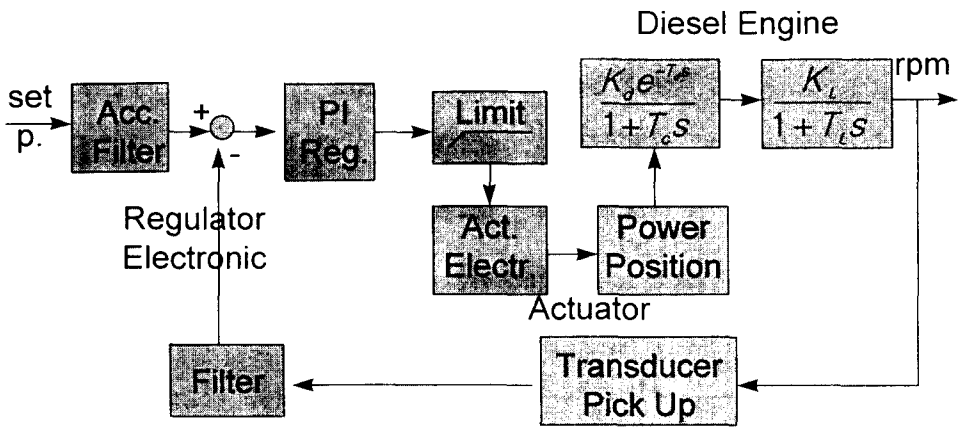


Fig. 2.5 Block Diagram of Norcontrol Company Study

Study of S.T.Lyngso company

They developed EGS900 system using MRAC(Model Reference Adaptive Control) as Fig.2.6.

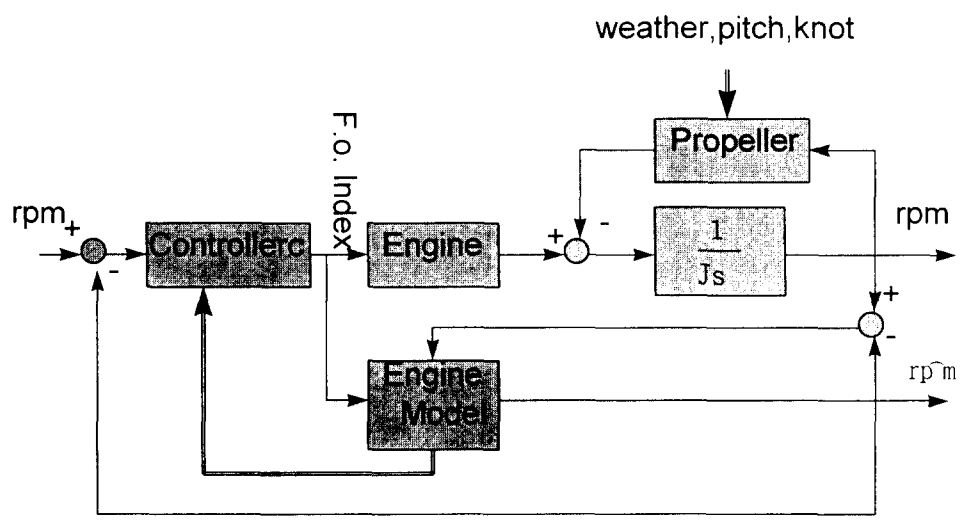


Fig. 2.6 Block Diagram of S.T.Lyngso Company Study

3 Various studies on the digital governor in Korea

In Korea studies on the digital governor of diesel engine started from when low speed large stroke marine diesel engine had been appeared and provoked speed control problems due to severe changes of various engine parameters especially engine dead time and gain due to increasing power and stroke while decreasing revolution per minute and numbers of cylinder as described in the introduction chapter.

Table 3.1 indicates what a severe changes occur to each parameters according to rpm in whole operating range of marine propulsion diesel engine with low speed, large stroke, small number of cylinder.

Table 3.1 Variation of Engine Parameter According to Operating Range

rpm	20	30	50	60	70	80
c constant						
L	1.5	1.0	0.6	0.5	0.43	0.38
Tc	0.07	0.05	0.03	0.03	0.02	0.02
Kc	16.3	22.9	58.2	81.9	103	122
KL	36.7	35.6	69.4	99.9	136	177
Kr	0.02	0.03	0.01	0.01	0.007	0.006
Tr	2.16	3.35	2.86	2.38	2.04	1.79

Study of Y.H.Yu and J.S.Ha

Yu et al model diesel engine of which combustion system is first order system with dead time and revolution system as first order and propose speed control system using optimal control theory as in Fig 3.1. Because in optimal control system if the parameters of controlled system become different from those of model, controlled variables may not be followed to the references , so they augment the system with the new state variable which integrate the difference of their rpm to accord reference rpm and real engine rpm even though parameters of modeled system are not consistent with those of real system by the various reasons.

Also in the rough sea control system is required with rapid response due to abrupt and large amounts of revolution change, they propose to insert feed-forward control path under assumption of known additional load by wave, tide and wind etc.

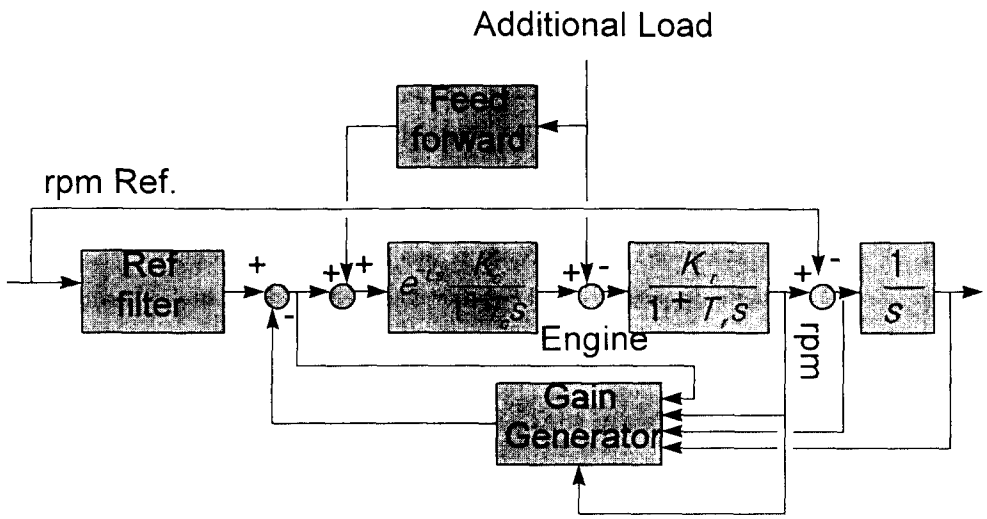


Fig 3.1 Block Diagram of Yu et al Study

They divide whole operating range of marine propulsion diesel engine by appropriate sections with investigation changing trends of each optimal gains and propose to use the optimal feedback gains of the divided section including operating rpm for practical usage. They construct the proposed system with digital computer and analog computer for hybrid simulation and practice various experiments under mock of real sea environments to validate practical application.

Study of B.D.Kim and J.S.Ha

Kim et al model combustion and revolution system of diesel engine as first order system each and propose PID control system of which parameters is tuned automatically with revised critical sensitivity method of Ziegler and Nichols by Kim as in Fig. 3.2.

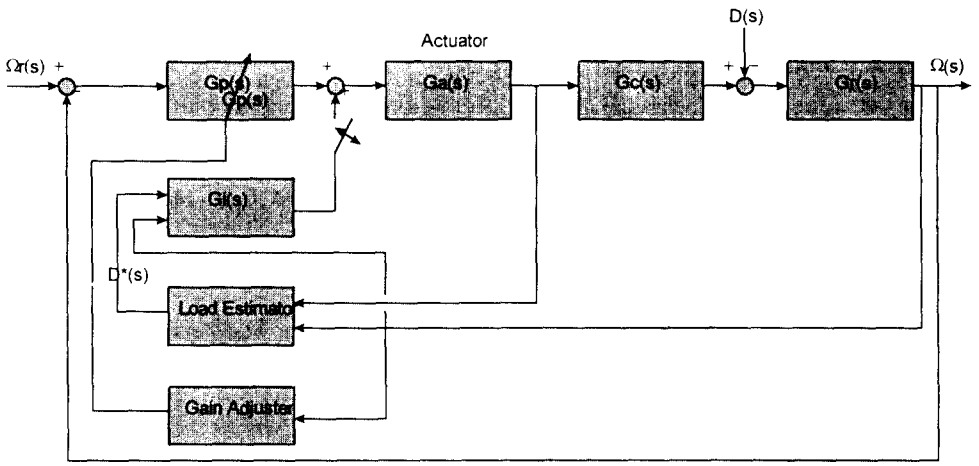


Fig 3.2 Block Diagram of Kim et al Study

Also they propose to insert intuitive controller which prevent engine rpm from severe change with feedback of engine torque using experimental knowledge of experts when the load torque of diesel engine change severely at the rough sea condition . They propose estimation method of load torque for this using the rpm and it's derivatives.

Study of M.O.So and J.S.Ha

So et al model combustion system and revolution system of diesel engine as first order system as in Fig 3.3 and study on the estimation of parameters. They propose modified least square estimation method which eliminate square item from conventional least square method under the assumption of known stochastic characteristics of measured noise.

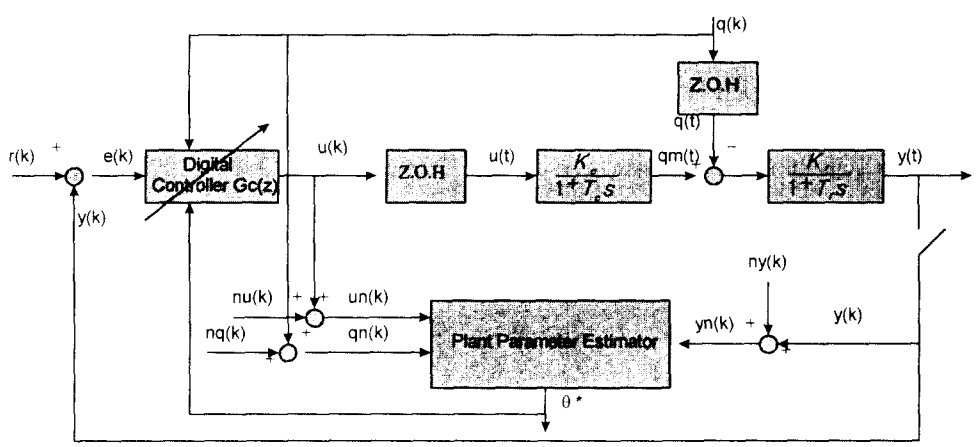


Fig. 3.3 Block Diagram of So et al Study

Study of B.G. Jung and J.H. Yang

B.G. Jung et al model of which combustion system is second order system with approximation engine dead time as first order system and revolution system as first order system. They propose $H\infty$ control system and μ-synthesis control system with feed forward path which parameters variations of diesel engine according to the change of operating range are handled with modeling uncertainty of that as in Fig.3.4.

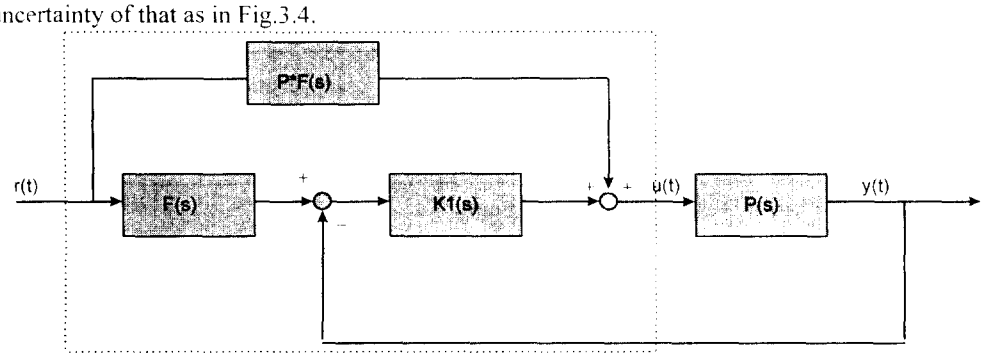


Fig. 3.4 Block Diagram of Jung et al Study

4. Market Prospects of Digital Governor In Korea

The market of digital governor is depend on the ship building market for marine use. But land use for the emergency diesel generator unit and power plant gradually increase because the lack of electricity bring forth often at the peak demand especially in summer season ,and maneuvering and monitoring system of generator unit is computerized ,and speed governor trends to be included in the those system. In 1996 forecast for the Korean Shipbuilding Industry is "Bright on the whole somewhat blunted growth" according to The KSA(Korean Shipbuilder Association). The KSA predicts a moderate 10 percent expansion in Korea's shipbuilding order winning with the Japanese Yen's change being a major variable. As the major reasons for its rosy forecast,

1. The increase in old vessels, 25 years or so, required for replacement.
2. The expansion in crude oil transactions which increase orders for tankers.

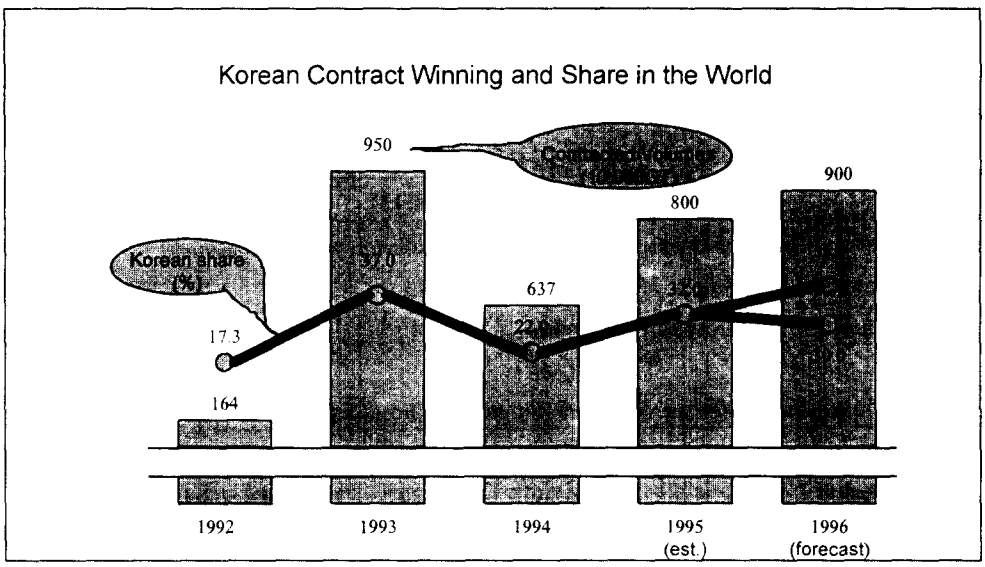


Fig. 4.1 Korean Share in World Shipbuilding Market

The Fig.4.1 indicates world market share of shipbuilding

Table 4.1 The Tendency of New Shipbuilding Order in the World

(UNIT; Million GT)

CLASSIFICATION	1995	1996(Forecast)
VLCC	8.0(20%)	20 - 22(55%)
Bulk(SUEZ - CLASS)	21.0(55%)	9 - 12(29%)
Container	6.0(16%)	2.5 - 3.5(8%)
The Others	3.6(9%)	2.5 - 3.4(8%)

- Note ; The Figures in Parentheses Denote Deals On The Korean Share

As explaining in the Introduction , recently it is almost used digital governor systems for marine propulsion engine . So we can image the market of digital governor with investigation of the plans for shipbuilding and marine propulsion engine.

Table 4.1 and 4.2 show shipbuilding plan and Table 4.3 for marine propulsion diesel engine manufacturing orders.

Table 4.2 Plans For New Shipbuilding Orders

(Unit : $100 Million)

CLASSIFIC ATION	1995(record)		1996(forecast)		Changes(%)
	No. of Ships	Amount	No. of Ships	Amount	
Hyundai	49(1)	28(0.5)	51(3)	30(2.5)	7

Daewoo	17	7.3	30(7)	20(3)	174
Samsung	37	8.19	37	19	-
Hanjin	15	9.5	13(5)	5(1.8)	-
Halla	20	10.6.5	33	15	131
Total	**138(1)**	**65.8(0.5)**	**164(15)**	**89(7.3)**	**35**

Note : 1.The figures in parentheses denote deals on a deferred payment basis.

2. The Korean Shipbuilding Capacity : 6.5 million GTS.

Source: The Export - Import Bank of Korea.

Table 4.3 Manufacturing Plan of Marine Propulsion Diesel Engine

Classification	Hyundai H.I	Korea H.I	Samsung H.I	Ssangyong H.I	Halla H.I
Engine Unit	106	44	24	Medium Speed 80 Others 132	NEW
Remark	14/12K98MC -C			Medium speed (1000 - 2000 BHP)HOLIBY L23/30, L28/32	PERKINS(England)Medium Speed(up to 2900BHP) New SULZER Diesel

Table 4.5 Various Projects Until 2000 for Shipping Company

Classification	Hyundai Merchant(HMMC)	HanJij Shipping	KGC(Korea Gas Corporation)	VLCC Project
Details	New Building 165 (Existing 39 -> 233) LNG, LPG, Product, Cruiser, Mammoth Container etc.	New Building 100 (Existing 56- >Abt 200) Mammoth Container, Bulk etc.	New LNG 10-13	KOTC(Kuwait): 300,000GTx3 BP(England): 300,000GTx3(4) MOBIL(USA): 300,000GTx2(2) CBM(Belgium): 300,000GTx1-2

It is particular thing that instead of steam turbine Dual Fuel Diesel Engine like L70MC-GI or L80MC-GI is being investigated to apply for LNG Carrier.

Besides marine usage of digital governor, land usage of it is increasing gradually.
Table 4.6 shows Diesel Power Plant Project to be carried out by Korean Company.

Table 4.6 Diesel Power Plant Project in 1996

Classification	Hyundai Heavy Industry	HanJung
MW x UNIT	12 x 3	12 x 3
	12 x 3	12 x 3
	12.5 x 4	30 x 4
	30 x 4	54.1 x 2
	20 x 5	20 x 3
	50 x 4	
	40 x 2	
	20 x 5	
	3.5 x 3	
TOTAL UNITS	33	15

5. Conclusion

We investigate the studies on the digital governor for low speed , marine propulsion diesel engine and medium speed diesel engine. With this investigation, almost all models of low speed ,long stroke marine propulsion diesel engine to design digital governor are considered engine dead time. And various kinds of control technique can be applied for the best performance, or design flexibility is very redundant. Because digital governor is a kind of computer, we can easily use many kinds of information from it for monitoring and maneuvering the engine. Because digital governor is composed of electronic chips except actuator, it can be easily manufactured in comparison with hydromechanic one.

Of course there are some problems in endurance and reliance of actuator and electronic parts, but these are able to fixed up with various methods and redundancy as well as these kinds of problems are also placed in other systems. Besides, there are many necessities for the engine to be automated in our industries. There are many constraints after developing the digital governor in the case of marine usage like the ship's classification, certificates, owner's designation and nominations etc. ,but because especially digital governor of medium speed diesel engine for land usage of emergency power plants can create a lot of demands for domestic usage, this item is fully worth while to invest for developing and practical application under the our industrial environment. So we deeply hope that this is opportunity for our enterpriser to be interest in this fields.

REFERENCES

1. **劉泳昊** "A Sdudy on the Speed Control of Maine Diesel Engine" 한국해양대학교, 1990.2
2. "The Meeting Minute On the Application of Woodward Governors to the B&W LMC Engine ", 1984, 6.
3. M.A.N - B&W, "Technical Note 870310", 2500/KEH/BBN(345)
4. G.E.Harland, K.F.Gill "Design of a Model Reference Adaptive Control for an Internal Combustion Engine", Measurement and Control Vol.6 April 1973, PP 176~173
5. P.E. Wellstead, C.Thiruarooran, D.E.Winterbone, "Identification of Turbo-charged Diesel Engine", 1978,Proceeding 7th IFAG world congress Helsinki, Filand
6. P.E.Wellstead, "Frequency Domain System Identification", In the S.R.C. vacation school on Stochastic processes in control, Uni. of Warwick
7. P.E.Wellstead, "Reference Signals for Closed Loop Identification", Int.J.control, 1977
8. Thiruarooran, "Diesel Engine Identification Study", Mechanical engineering depart. report, UMIST, 1977
9. **北川正人**, "**船舶 主機** エコミ"コの **回轉數 制御** ミステムの **理論 解析**", ナフ"コ **技報** No.61, 1986.1
10. サトウ, "MG-800 カ"ハ"ナミステムの **開發**, ナフ"コ **技報** No.64, 1987.8
11. **田村直樹** "**電子**カ"ハ" ナ **制御** パウメータ **決定** ミステムの **開發**", ナフ"コ **技報**, No.65,1988.1
12. Y.Murayama, T.Terano,S.Masui,N.Akiyama, "Optimizing Control of a Diesel Engine"
13. Norcontrol, "Digital Governor System DGS8800" Doc.No.0759A, 1983
14. Norcontrol, "Digital Governor DGS8800 System Information", 1985.3
15. S.T.Lyngso, "Electronic Governor System EGS900" CI 900.166.623 version 2.01,1987,7
16. S.T.Lyngso, "Electronic Governor System EGS900" STL 07.A.32 version 2.02
17. Norcontrol, "Technical Analysis of Governaor for B&W 6L80MCE"
18. P.A.Hazell, J.O.Flower, "Sampled Data Theory Applied to the Modelling and Control Analysis of Compression Ignition Engine - Part I", Int.J.Control., Vol.13, No.3 PP549~562,1971
19. P.A.Hazell, J.O.Flower, "Sampled Data Theory Applied to the Modelling and Control Analysis of Compression Ignition Engine-Part II", Int.J.Control., Vol.13, No.4 PP609~623,1971
20. P.A.Hazell, J.O.Flower, "Discrete Modelling of Spark Ignition Engines for Control Purpose", Int.J.Control, Vol.13, No.4, 1971
21. **蘇明玉** "A Study on the Parameter Estimation for the Optimal Speed Control of a Diesel Engine", 한국해양대학교, 1989.2
22. **金秉德** "A Study on the Improvement of Speed Control Performance on s Diesel Engine" 한국해양대학교, 1944.2
23. 정병건 "선박용 디젤기관의 로바스트 속도제어기 설계에 관한 연구" 부산수산대학교, 1996.2

24. 宋文鉉 "A Study on the Adaotive Speed Control of Static Rotational Systems by Means of the Nominal Model Tracking Method" 한국해양대학교, 1996.2