THE AUTOMATIC OPERATION OF A TRIPLE GENERATOR GAS-MAKING PLANT.

By L. L. Pemberton.

The engineering world has advanced through many phases, and the present epoch might well be termed the "Automatic Age." More and more industrial machinery and industrial plants are being operated automatically. Work, which formerly required an army of men, is being done by automatically-operated machinery, in charge of one or two skilled operators.

Not only does this save labour charges, but arduous and monotonous tasks can be performed with a degree of certainty and regularity with a properly-designed mechanism which would be quite impossible with manual effort.

The scope for the designing engineer alone these lines is unlimited; the problems to be met and solved are many and varied.

The industrial plant to be considered in this paper is a Complete Gasification Plant. It is used in the production of town gas from coal, brown coal, briquettes, or coke, with the addition of fuel oil or coal tar to enrich the gas produced to the desired calorific value.

It is intended to deal with the process of gas-making only sufficiently to illustrate the problem set the designer in evolving an automatic operating gear.

The Plant and Process.

The plant consists fundamentally of three brick-lined steel generators, in which the fuel is converted into gas. These are fitted with necessary inlet and outlet pipes and valves, which will be described more fully later.

The process, a special patented one, the details of which are beyond the scope of this paper, is briefly as follows:—Fuel in each of the three generators in turn is brought up to the desired temperature with an air blast, while the top of the generator is open to the atmosphere. After closing off the air blast, and closing the generator outlet or stack valve, steam is blown through the incandescent bed to form gas. Fuel is added in measured quantities at desired periods, and oil or tar is sprayed on the fuel bed for a certain time during each cycle.
The essential pipes and fittings for each generator are:

1. A fuel charger, that is, a means for measuring a charge of fuel and depositing it into the generator without opening it directly to the atmosphere.

2. A revolving grate fitted to the bottom of each generator. This must be designed to keep the fuel bed agitated, crush the clinker formed, and remove a certain amount of spent fuel, in the form of ash and clinker, continually. The ash must be removed in such a way that the generator will not be directly opened to atmosphere during gas-making.

3. A blow valve must be fitted in the blast main from the blower to the bottom of each generator.

Fig. 1.

5. A gas valve fitted to a gas main leading from the bottom of each generator.

6. A stack or outlet valve in a flue from the top of each generator, opening to the atmosphere.

7. An oil valve for spraying oil into the top of each generator.

8. A cross-over valve in a pipe connecting the tops of the generators together.

A diagrammatic layout of the plant is shown in Figure 1.

In operation one generator would be “blowing” (air blast in at the bottom, stack open at the top, all other valves to it closed), while the other two generators are gas-making. If No. 1 generator is “blowing,” No. 2 and No. 3 generators would be gas-making. No. 2 “Up-running” and No. 3 “Down-running”—that is, steam would be admitted to the bottom of No. 2 generator, and after going up through the fuel bed, would pass to the No. 3 generator, the cross-over valve between No. 2 and No. 3 generator being open for that purpose. The gas produced would then go down through the fuel bed and out the open gas valve from the bottom of No. 3 generator, all other valves to these two generators being closed.

At the end of a given time the process of gas-making in generators No. 2 and No. 3 is reversed. That is, the steam valve to No. 2 generator and gas valve from No. 3 generator closes, while gas valve from No. 2 generator and steam valve to No. 3 generator opens. This reverses the flow and purges No. 3 generator free of gas. At the next change No. 3 generator goes on to “blowing,” No. 1 generator (which has just been “blowing”) on to “Up-run” and No. 2 generator (which has had an “Up-run”) goes on to “Down-run.” So in one complete cycle each generator gets—a “Blow,” an “Up-run,” a “Down-run” and a “Purge.” At any one time two of the three generators are gas-making, while the third is blowing. During each cycle each generator is charged with a measured amount of fuel (usually at the beginning of the “Up-run”). Also once per complete cycle each generator is sprayed with oil or tar, generally at the beginning of the “Down-run.”

The time for one complete cycle is approximately 15 minutes. During that time the following valves have to open and close at exactly the right time and in the right order:—
3 Fuel Charger Gate Valves Open and Close Once.
3 Fuel Charger Bell Valves Open and Close Once.
3 Blow Valves Open and Close Once.
3 Steam Valves Open and Close Twice.
3 Gas Valves Open and Close Once.
3 Stack Valves Open and Close Once.
3 Oil Valves Open and Close Once.
3 Cross-over Valves Open and Close Once.

24 valves in all, 21 of which open and close once per cycle, and three which open and close twice per cycle. A time diagram showing the approximate time of opening and closing each valve for one complete cycle is shown in Figure 2. As this plant is required to operate on various fuels, it is essential that these times can be varied over a wide range. Different combinations of settings can then be tried to ascertain the one which gave the best results.
Choice of Operating Medium.

The majority of valves being large, and requiring a good deal of power to open and close them as well as being remotely separated, a hydraulic system was chosen as being the most suited to this purpose. Each of the main valves would be fitted with a hydraulic cylinder, operated by a pressure of 800 lbs. per square inch, supplied by the works hydraulic engines and accumulator.

Interlocking.

To design a mechanism which will operate a plant of this nature does not call for any special ingenuity. It is, however, a very different problem to design one which cannot be operated incorrectly or unsafely. The first consideration was to interlock certain valves so that an unsafe combination could not be obtained. For example, the blow valve must never open to admit air into a closed generator. The stock valve from that generator must always open first. As the gas out and the blow mains are joined together before entering the bottoms of the generators, these two valves on the same generator must never be open together. The opening of the steam valve at the bottoms of the generators must synchronise with the opening of the cross-over valve and a gas valve on the next generator. To interlock the gas, blow, and stack valves, the hydraulic cylinder coupled to the stack valve was made to operate a locking bar on both gas and blow valves. This was arranged in such a way that a blow or gas valve could be unlocked and opened separately, but not both at the one time. When the stack valve is open the gas valve is locked closed. When the stack valve is closed the blow valve is locked closed. The stack valve cannot close until the blow valve is closed, and cannot open until the gas valve is closed.

To ensure correct timing of the steam inlet to generators a special valve was designed. This consisted of a 2 in. bore double-faced parallel slide-gate valve, the slide being attached to a rod through a gland to a crosshead. The crosshead sliding on two guide rods is spring loaded to keep the valve closed. The crosshead is raised and the valve opened by four quadrant levers operating two roller chains around a roller, one on each side of the crosshead. With all levers in the "Off" position, or with one lever in the "On" position and three in the "Off" position, or one lever on each side on the "On" and one on each side on the "Off" position, the valve remains closed. If, however, the two levers on either side are brought to the "On" position the valve opens. This is achieved by allowing sufficient
slack in the operating chain so that the movement of one lever and its quadrant merely takes up the slack of the chain, the movement of the second lever on the same side opening the valve. The chain is looped from one lever quadrant under one roller on the crosshead to the quadrant on the other lever on the same side. The four levers on each steam valve are attached by a suitable link mechanism to the cross-over and gas valve—that is, the levers of the steam valve on No. 1 generator would be attached to gas valve No. 2 and No. 3 generators and cross-over valves between Nos. 1 and 2 generators and Nos. 1 and 3 generators, the opening of any one of these valves bringing the lever to the “On” position and closing the valve to the “Off” position.

With this arrangement the opening of the cross-over valve between Nos. 1 and 2 generators and gas valve, No. 2 generator causes steam valve No. 1 to open also. The closing of either of these valves closes it again. This is brought about by linking these two valves to levers on one side of the steam valve. Gas No. 3 and cross-over between Nos. 1 and 3 generators would be linked to the other side of No. 1 steam valve, and would operate in a similar manner. The other two steam valves are coupled in the same way to their respective cross-over and gas valves.

Charges of solid fuel, before entering a generator, go through two valves, firstly through a gate valve into a chamber; then, after the gate valve has closed, the fuel passes a bell-shaped valve into the generator. These two valves are hydraulically operated and mechanically interlocked, so that only one can open at a time.

**Automatic Operator.**

Having covered the necessary interlocking of the various valves, the next problem was to design a suitable automatic operator or control machine. This had to be of such a nature that each of the valves could be operated at will by the attendant, and when desired the machine could be set to automatically open and close them in their correct order and timing. Also, should any fault develop, the machine must close the plant down to a safe position, that is, with stacks open and all other valves closed, and give audible and visible warning that this had been done.

Figure 3 shows a general arrangement of the Automatic Operator designed for this purpose.
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Fig. 4.
Figure 4 shows a diagrammatic view of the high pressure hydraulic piping from the Automatic Operator to the various valves.

A brief description of the Operator is as follows:—Consisting firstly of a row of 19 pilot hydraulic valves, and secondly a means for operating these valves both manually and automatically. The pilot valves are connected to the main operating cylinders of the hydraulically-operated valves as follows:—

3 Fuel Chargers (the charger bell valve of one generator is coupled in parallel with the charger gate of the next).
3 Gas Valves.
3 Blow Valves.
3 Stack Valves.
3 Cross-over Valves.
3 Oil Valves.

and one to the shut down cylinder of the controller, which will be described later. Total nineteen pilot valves.

For manual operation each pilot valve is provided with a hand lever. Pulling all the levers forward opens all the pilot valves to drain. This allows the constant pressure on the ram side of the hydraulic cylinders (this side being always connected to the hydraulic mains), to force the pistons and rams into their cylinders. The hydraulic cylinders are so arranged that this action opens the stack valves and closes all other valves, thus bringing about the safe shut-down position of the plant.

Pushing a lever back operates the pilot valve connected to it in such a way as to close the drain and connect the main hydraulic pressure to the end of its hydraulic cylinder away from the ram. The water pressure in both ends of the hydraulic cylinder is now the same (800 lbs. per square inch). The effective area of one end is the cross section area of the cylinder, and that of the other end the cross section area of the cylinder minus the cross section area of the rod. The first area must therefore always be the greater, so the total force at that end will be the greater, and the piston is now forced to the outer end of the cylinder. This action would close a stack valve or open any other valve.

For automatic operation these levers are operated mechanically by means of a rocker shaft, the times of operation being controlled by two cam shafts.

Driving power for the operator is obtained from a 1 H.P., 3-phase A.C. motor running at 1450 R.P.M. This is directly coupled to a 40 to 1 ratio reduction gear box. Attached to
the output shaft, which would revolve at about 36 R.P.M., is an eccentric. This operates the rocker shaft, imparting to it 36 strokes per minute. Also coupled to the slow-speed shaft of the first gear box is the input shaft of a 3 to 1 ratio P.I.V. variable speed gear box. The output shaft of this gear box is coupled to a second reduction gear box, with a ratio of 544 to 1. With the variable speed gear set at 1 to 1 ratio the output shaft of the second gear box revolves at one revolution in 15 minutes. By varying the ratio of the variable speed gear box this final output speed can be varied from one revolution in \( \frac{74}{3} \) minutes to one revolution in \( 22\frac{1}{4} \) minutes.

The two cam shafts are driven from this output shaft 1 to 1 ratio. Therefore, the cam shafts can be set to revolve at any rate between \( 7\frac{1}{4} \) and \( 22\frac{1}{4} \) minutes per revolution.

The cams are in gangs of three, each one having a notch cut in its periphery. In each gang these notches are cut at 120° to each other. Each gang controls the three corresponding valves in the plant—e.g., three stack valves, one in each generator. Therefore, whatever setting is given to the gang of cams, these three valves always operate with one-third of a cycle spacing. The dropping of a lever into the notch as the cam revolves sets the time at which the corresponding pilot valve is operated. The lever allows a pawl to fall into the path of the constantly-oscillating rocker, which then operates a cross slide attached to the hand lever of the pilot valve. One cam shaft controls the levers and pawls, which engage with the rocker in such a way as to make it move the cross slides in a forward direction. The other cam shaft controls the reverse operation of the cross slide. As the slides are attached to the pilot valves, and the pilot valves supply hydraulic pressure to the main valves, so it follows that one cam shaft controls the time of opening of the stack valves and the closing of all other valves. The other cam shaft controls the closing of the stack valves and the opening of all other valves.

The times shown on Figure 2 for the opening and closing of the various valves are only approximate, and as the plant is required to be able to operate on different fuels such as bituminous coal, coke, or brown coal, it must be possible to vary these times over the complete cycle. Also the setting must be easy to make and repeat, and positive when made. A cam which slipped out of setting would of course be disastrous. The cam setting and clamping gear were designed on the vernier principle. It is illustrated in Figure 5, which shows one bank of three cams attached to one of the shafts. The sleeve is rigidly pinned to the shaft, and has a head at
one end with 31 teeth on its inner face. The other end of the sleeve is screwed to take a ring nut. The cam bank, consisting of three cam discs, 6 inches diameter, attached together by a smaller cylindrical portion, is a sliding fit on the sleeve. One end of the centre portion has 30 teeth cut round its face. A loose collar, also a sliding fit on the sleeve, is fitted between the cam bank and the head of the sleeve. This collar has 31 teeth on one face and 30 teeth on the other, to fit between the teeth on the sleeve head and cam bank respectively. When the whole unit is assembled, as shown in Figure 5, with the ring nut screwed against the outer end of the cam bank, the cams through the intermeshing teeth are positively clamped to the shaft. To vary the relation of cam and shaft it is only necessary to slack back the ring nut sufficient to allow the teeth to become disengaged, and the cam bank can then be rotated in relation to the shaft and set in a new position. Owing to the vernier action of the 30 and 31 teeth, $30 \times 31 = 930$ positive settings can be obtained in one revolution. Therefore, at mean cam shaft speed of one revolution in 15 minutes a variation of less than one second can be obtained.

**Automatic Shut Down.**

The nineteenth hydraulic pilot valve controls the hydraulic supply to a cylinder operating the “Shut Down” mechanism.
The hand lever operating this pilot valve is placed on the outside of one end of the operator. It has two positions, labelled "Start Up" and "Shut Down."

In the latter position the pilot valve opens the outer end of the hydraulic cylinder to drain, and the ram is forced into the cylinder by the constant pressure on the ram end. This moves downwards an interrupted rack attached to the ram, which, by engagement with a pinion attached to the shaft, causes the shaft to rotate, and rockers on it force all the pilot valve slides forward. This locks the mechanism in the safe shut-down position. At the same time a switch is tripped stopping the driving motor. When the lever is placed in the "Start Up" position the pilot valve supplies pressure to the other end of the hydraulic cylinder. The ram and rack attached to it move upwards, rotating the rocker shaft, freeing the slides and mechanism of the operator. By means of another hand lever, which has two positions labelled "Hand" and "Auto," the "Shut-down" ram can be stopped in mid position. In this position the pilot valve levers and slides are free to be operated by hand while the automatic mechanism remains locked. A spring-loaded plunger tends to force the "Shut-down" lever to the "Shut-down" position. The lever is held in the "Start-up" position by means of a catch, which is held in engagement by an electric solenoid. A break in the solenoid circuit, de-energising it, would allow the catch to disengage, and the spring to force the lever to the "Shut-down" position. The solenoid circuit, which will be described more fully later, is used to check the correct sequence of valves at each change of cycle. An incorrect sequence would interrupt the solenoid circuit, allow the lever to move to the "Shut-down" position, and so cause the plant to shut down safely with stacks open and all other valves closed. At the other end of the automatic operator, attached to the cam shafts, are dials. These indicate the exact positions of the cams. A crank handle attached to one of the shafts and a spring-loaded pin can be used to free the shafts by the driving mechanism. The cams can then be turned by hand to any desired starting position.

*Electric Check and Indicator.*

A specially-designed electric switch is fitted to each of the main valves. These consist of two double pole, double throw, quick make and break switch mechanisms, robustly constructed and enclosed in a dust tight case. The switch contacts are operated by the valves through suitable trip mechanisms. One set of contacts makes and the opposite set breaks when a valve is closed, and the reverse occurs when the valve is opened.
Two separate circuits are connected to these switches. One circuit is for indicating the valve positions, and the other is for checking the correct sequence of valves.

A panel laid out similar to Figure 1, with a red and a green light in the position of each valve, is used as an indicator. When a valve is closed, operating its switch, the green lamp lights, and when it opens the red lamp lights. So the attendant can at a glance see which valves are open and which are closed. The other circuit is used to relieve the attendant of checking at each cycle change that the correct valves have opened. This circuit consists of the one half of the valve switches not used for the indicator lamps, a contactor drum, and the “Shut-down” solenoid previously mentioned.

The contactor drum is mounted at one end of the automatic operator, and is driven by one of the cam shafts. Sectioned contact strips are arranged around it, and stationary collector fingers make contact with them.

The strips are bridged, and the collectors are wired to the switches in such a way that only a correct sequence of valves will give a closed solenoid circuit. Any one valve in an incorrect position will break the circuit, and so cut off the electric energy from the solenoid, causing it to shut the plant down. When this is done a relay arranged in the circuit makes contact with an electric siren, which warns the attendant.

To prevent a break of circuit during the change of cycle, when some valves are opening and some are closing, the switches are short circuited for a brief period. To do this a separate pair of collector fingers and contact strips are arranged at one end of the contactor drum. These strips are placed at the change of cycle position, so that the collectors contact them just before the first valve is due to move. The length of the strips is such that the last valve to move has just reasonable time to reach its new position before the contactors disengage with them. So a constant check after every change of cycle is kept on the plant.

The main aims when designing the operating gear described in this paper were to make the plant:

1. Definitely safe and fool proof.
2. Sufficiently elastic and adjustable to cover any reasonable alterations and settings required.
3. As fully automatic and reliable as possible.

The operation of this plant over the past twelve months has demonstrated the complete reliability of the automatic controlling mechanism.