

DUPLEX COMMUNICATION CONTROL DEVICE

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BACKGROUND OF THE INVENTION1. Field of Invention

The present invention relates to a duplex communication control device used with a communication system consisting of a plurality of communication stations connected with a duplex communication network. More specifically, the invention relates to a duplex communication control device capable of being used with a distributed control system that is required to have high reliability to control process variables such as temperature and pressure in a communication system where various communication stations connected with a duplex communication network communicate with each other by token passing, i.e., a token is passed from station to station.

2. Description of the Prior Art

A communication system consisting of a plurality of communication stations sharing one communication network is required to control communication in such a way that communication between the stations is carried out in an orderly manner.

Token passing communication control has been heretofore known as a communication control method of this kind. Examples of communication system utilizing token passing are disclosed, for example, in U.S. Pat. No. 4,058,681 issued to Imaizumi et al. and U.S. Pat. No. 4,491,946 issued to Kryskow, Jr. et al. In these



disclosed token passing communication control methods, a single token permits each station itself to serve as a master station and to communicate with other stations, using a communication network. The token is successively passed from station to station in terms of token frames in a predetermined sequence. When one communication station receives this token, it controls the whole communication system and, if a request for communication exists, communicates with other stations. If any request for communication does not exist, the token is sent to the next communication station. The cyclic passing of the token frames is managed according to station addresses intrinsic to individual stations. When token frames are passed to the next station, the token frames are normally sent to the station having a station address which is larger than the station address of the present station by one.

This token passing communication control method efficiently uses the communication network. Also, communication control is not centralized. Furthermore, the control is not affected by the length of the communication network. In this way, the token passing has various features. Hence, it is widely accepted in process control systems.

In process control systems required to have high reliability, field control stations assigned to control the process and the communication network to which the field control stations are connected are duplexed. When one fails, the other backs up it.



Fig. 1 is a conceptual diagram of one example of communication system consisting of a plurality of communication stations ST1, ST2, etc. connected with a duplex communication network consisting of lines BS1 and BS2. In this communication station, if a trouble occurs at a point A in one communication line BS1, and if the token arrives at the communication station ST1, it is assumed that this station begins to send a token frame toward the communication station ST2, for example, using the first communication line BS1, at first. Then, the transmission is unsuccessful because of the trouble with the line BS1. Therefore, the station ST1 then executes transmission of the token frame, using the second communication line BS2. This transmission will succeed.

In this case, the communication station ST1 informs every communication station connected with the communication network that the first communication line BS1 is at fault when the token is passed to the station ST1. On receiving this message, every station recognizes the failure in the first line BS1 and stops the communication function using the first line BS1. Subsequently, the communication is continued, using the second line BS2.

However, this communication system controlling the communication in this manner has the following problems.

(a) Since the communication station ST1 informs the other stations of the failure in the first line BS1 when the token is again passed to the station ST1 after the failure in the first line BS1 is detected, the other stations cannot recognize the failure



in the first line BS1 until the token is passed to the station ST1 again.

(b) If any one communication station fails to receive the message indicating that the first communication line is at fault, this station will never recognize the failure in the line BS1.

(c) If any one communication station not recognizing the failure in one communication line exists, then this station will repeat the operation for detecting failure in one communication line whenever the token is passed to this station. This deteriorates the performance of the communication system. Also, a warning message of failure in one communication line will be repeatedly issued.

(d) When one communication line is at fault, if a new communication station is connected with the communication network, then this station is unable to recognize the failure in one communication line.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a reliable duplex communication control device which, if one of the two communication lines is at fault, permits every communication station connected with the network to recognize information about the failure with certainty and quickly and which minimizes the effects on normal communication operation.

It is another object of the invention to provide a duplex communication control device which, if a new communication station



is connected with the communication network, permits the new station to quickly recognize the states of the communication lines without adopting complex procedure and to smoothly participate in token passing communication.

It is a further object of the invention to provide a duplex communication control device which prevents a token from being held by two communication stations simultaneously if the communication network is disturbed by the effects of noise and the system is again set up or if the same station address is assigned to two or more stations for some reason.

It is a yet other object of the invention to provide a communication control device which, if this communication control device connected with a communication network is at fault, disconnects from the network to prevent communication between other stations from being affected by the fault.

It is a still other object of the invention to provide a reliable duplex communication control device which, if every station is duplexed, is capable of certainly diagnosing the communication control device incorporated in every operating or controlling communication station and the communication control device incorporated in every standby communication station.

Other objects and features of the invention will appear in the course of the description thereof which follows.

BRIEF DESCRIPTION OF THE DRAWINGS



Fig. 1 is a conceptual diagram of a communication system consisting of a plurality of communication stations connected with a duplex communication network;

Fig. 2 is a conceptual diagram of a communication system according to the invention;

Fig. 3 is a block diagram of the internal structure of the communication station ST1 shown in Fig. 2, the station serving as an operator station;

Fig. 4 is a block diagram of the internal structure of the communication stations ST2, ST3, etc. shown in Fig. 2, the stations ST2, ST3, etc. serving as field control stations;

Fig. 5 is a conceptual diagram of main components of the communication control device FCA incorporated in each communication station shown in Figs. 3 and 4;

Fig. 6 is a conceptual diagram of a token frame in a transmission frame delivered from the transmission-reception control means shown in Fig. 5;

Fig. 7 is a conceptual diagram of the bus status list 21 in each communication station;

Fig. 8 is a flowchart illustrating the operation of one communication station connected with the communication network HF shown in Figs. 2-5;

Fig. 9 is a block diagram of other example of the transmission control device FCA according to the invention;

Fig. 10 is a block diagram of another example of the



transmission control device according to the invention;

Fig. 11 is a flowchart illustrating the operation performed when one communication station obtains a token;

Fig. 12 is a block diagram of a further example of the communication control device according to the invention;

Fig. 13 is a block diagram of a duplex communication station acting as a field control station;

Fig. 14 is a block diagram of a still other example of the communication control device according to the invention;

Fig. 15 is a flowchart illustrating the operation performed when the communication station shown in Fig. 14 is connected with the communication network HF;

Fig. 16 is a block diagram of a yet other example of the communication control device according to the invention; and

Fig. 17 is a flowchart illustrating the operation of the device shown in Fig. 16.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to Fig. 2, a communication system according to the present invention is conceptually illustrated. In this embodiment, it is assumed that the communication system is a process control system. A plurality of communication stations ST1, ST2, etc. each of which constitutes a unit of communication are all connected with a duplex, bidirectional communication network HF consisting of a first communication line L1 and a second communication line L2. Each station STi is coupled to the



communication network HF by a pair of couplers Ci. Each station is equipped with a communication control device which controls communication by token passing.

The communication station ST1 is an operator station which permits a human operator to monitor the whole system. This station ST1 gives instructions about control operations and has a keyboard and a graphic display acting as a man-machine interface. The other communication stations such as ST2 and ST3 are distributed field control stations and control the process under the control of the operator station and under the instructions given from the operator station.

Fig. 3 is a block diagram showing the internal structure of the communication station ST1 acting as the operator station. This station includes a communication control device FCA, a central processing unit CPU, a main memory unit MM, and an input/output control unit IOC. The communication control device FCA is coupled to the duplex communication network HF via a pair of couplers and connected with the processor unit CPU, the main memory unit MM, and the input/output control unit IOC via an internal bus BS.

The communication control device FCA comprises a processor used only for communication and a peripheral circuit. The device FCA executes communication processing independent of the processor unit CPU at the request of other unit or other communication station. This processing utilizes token passing, i.e., when a token is passed to the station itself, communication processing is



performed by the use of the duplex communication network HF. If both lines L1 and L2 of the duplex network are normal, both lines L1 and L2 are alternately used, or a predetermined one is employed. If one communication line is at fault, the normal one is used.

The processor unit CPU performs various kinds of internal data processing as the operator station. When the need of communication arises, the processor unit CPU prepares commands or data used for communication in a transmission buffer included in the main memory unit MM, and delivers a communication request to the communication control device FCA according to the kind of communication. The results of communication made under the control of the communication control unit FCA are stored in a reception buffer. The processor unit CPU utilizes the stored data as the need arises.

A keyboard DSP and a graphic display acting as a man-machine interface are connected with the input/output control unit IOC. A typewriter and other devices (not shown) are connected via the input/output control unit IOC.

Fig. 4 is a block diagram showing the internal structure of each of the communication stations ST2, ST3, etc., acting as field control stations. The internal structure of each station is essentially the same as the internal structure of the communication station ST1. Each of the stations ST2, ST3, etc. comprises a communication control device FCA connected with the duplex communication network HF via a pair of couplers, a central processing unit CPU connected via an internal bus BS, a main memory



unit MM, and an input/output control unit IOC. Actuators such as sensors and valves installed in the process control device are connected with the input/output control unit IOC directly or via a field bus.

Fig. 5 conceptually illustrates main components of the communication control device FCA included in each communication station ST_i. This control device FCA includes receivers 11 and 12 which receive communication frames sent over the first communication line L1 and the second communication line L2 of the duplex communication network HF. Drivers 13 and 14 transmit communication frames through the communication lines L1 and L2. The control device FCA is further equipped with a transmission-reception communication control means 15 connected with the receivers and with the drivers. This control means 15 controls the token passing communication, sends and receives communication frames, checks data, and performs other functions.

A bus status list 21 stores bus status information indicating whether the communication stations connected with the two communication lines L1 and L2 can communicate by the use of the two lines L1 and L2. The list 21 is included in the memory inside the communication control device FCA or in a part of the memory unit MM. A token-generating means 22 serves to transmit a token, i.e., an authorization to control the system. When one station holds a token, if a token frame is sent to the next station, the token-generating means 22 carries the newest bus status information



possessed by said one station on the token frame and transmit them. A list-updating means 23 receives the token frame transmitted over the two communication lines L1 and L2 and updates the contents of its own bus status list 21 according to the bus status information carried on the token frame.

When the communication frame is transmitted, the transmission-reception control means 15 refers to the bus status list 21. If the information stored in this list indicates that none of the two communication lines L1 and L2 are at fault, then the two lines L1 and L2 are alternately used or a predetermined one is used. If one of them is at fault, the communication line not at fault is selected. The communication frame is sent over the selected line.

Fig. 6 conceptually illustrates the token frame of the communication frame delivered from the transmission-reception control means 15. This token frame comprises a preamble portion PRA indicating the head of the frame, address information DA about the addressed communication station, address information SA about the transmitting communication station, length information LG about the communication frame, control information CTL containing information indicating the kind of the token frame and control information for transmitting information, bus status information BI for the newest bus status (information indicating whether the communication lines L1 and L2 can be used or not), and a check code CRC. One kind of token frame is a normal token frame for sending the token only to those communication stations which presently



participate in the communication. Another example of token frame is a diagnostic token for passing the token to a communication station which does not currently participate in the communication but may participate in the communication in the future.

Fig. 7 conceptually illustrates the bus status list 21 incorporated in each communication station. Data indicating the newest state of each of the communication lines L1 and L2 are stored in this list. For example, state 1 indicates that the communication line is normal, while state 0 indicates that the line is at fault. If a communication line is normal, or in state 1, it follows that communication over the communication line is possible. If a communication line is at fault, or in state 0, it follows that communication over the communication line is impossible. When one station gains a token and sends out a communication frame, the station can know whether this transmission is successful or not, based on the bus status information as described above. The obtained newest information about the bus status is stored in the list. When one station receives the token, the list-updating means 23 updates the contents of the list according to the bus status information carried on the token. In this way, the contents of the bus status list 21 are updated quickly and changed into the newest bus status information.

The operation of the apparatus constructed as described above is next described. Fig. 8 is a flowchart illustrating the



operation of one communication station connected with the communication network HF. For example, a token is present in the communication station ST1 at first. The transmission-reception control means 15 refers to its own bus status list 21. The information is carried on the token frame. A destination address indicates the next station ST2. The information is transmitted over the communication line, e.g., L1, regarded as normal by the bus status list 21 (step 1). A decision is made to see if the transmission of the token is successful, by checking the acknowledgment signal from the communicating station (step 2). If the transmission of the token is successful, then the token is shifted to the addressed communication station ST2.

If the result of the decision made in step 2 is that the transmission of the token is unsuccessful, i.e., no acknowledgment signal is sent from the communicating station, then the station ST1 regards the communication line L1 as at fault and carries bus status information indicating that the line L1 is at fault on the token. Then, the token is transmitted over the communication line L2 (step 3). Thereafter, a decision is made to determine whether the transmission of the token over the line L2 has successful or not (step 4).

If the result of the decision is that the transmission has been successful, then the station ST1 updates the contents of its bus status list 21 so as to indicate that the line L1 is at fault. Also, in the communication station ST2 receiving this token, the



list-updating means 23 updates the contents of its own bus status list 21 and changes them into the newest information according to the bus status information (information indicating that the line L1 is at fault) carried on the token (step 5).

If there is a request for transmission of data or other communication, the communication station ST2 gaining the token executes the communication operation. Then, the station ST2 transmits the token to the next communication station, or the station ST3, over the line L2 according to the contents of its own bus status list 21 in the same way as the foregoing, i.e., the bus status information is carried on the token and transmitted.

By carrying out the above-described series of operations, the contents of the bus status lists of the communication stations are updated so as to represent the newest condition when the token is cycled through the stations participating in the communication.

If the result of the decision made in step 4 is that the transmission of the token over the communication line L2 is unsuccessful, then given processing for confirmation is carried out. As an example, transmission of the token over the line L2 is retried. A check is made to see if an effective response is not obtained. Similarly, the token is transmitted over the line L1. If no response is obtained, then the communication lines L1 and L2 are judged to be at fault. The defective locations are detected.

Fig. 9 is a block diagram of other example of the communication control device FCA according to the invention. In this embodiment,



each communication station is equipped with a diagnostic token-generating means 31. The diagnostic token generated by the diagnostic token-generating means 31 urges either a new communication station connected with the first line L1 and the second line L2 or a station whose power supply is turned on to participate in the communication. The newest bus status information held by the station itself is carried on the diagnostic token and transmitted.

If the list-updating means 23 receives the diagnostic token, the updating means updates the contents of the bus status list 21 held in the station according to the bus status information carried on the diagnostic token frame.

A live list 40 indicates the state of operation of the communication stations which have been or will be connected with the communication lines L1 and L2. In this embodiment, each communication station either participating in the communication or operating is termed an active station. Each station not participating in the communication is termed an inactive station. This live list is updated by receiving information which is transmitted by each communication station at regular intervals of time and which indicates that the station is in active condition.

The diagnostic token-generating means 31 refers to this live list 40 and sends a diagnostic token at regular intervals of time to those stations which are inactive in the list. Normal token generated by the token-generating means 31 is cycled through the



stations which are active in the live list 40.

In this embodiment, when a new communication station participates in the token passing communication, the status information on the duplex communication network can be made coincident with the information about the other communication stations without the need to take complicated steps.

In this configuration, the bus status information indicating failure in the duplex communication network and indicating whether the defective stations have recovered can be quickly and certainly sent to every communication station. Deterioration of the performance of the communication due to erroneous bus status information can be prevented. Where the system recovers from failure, it can immediately shift to normal operation of duplex communication network and, therefore, a reliable duplexed system can be realized.

In the embodiment of Fig. 9, when a new communication station participates in the token passing communication, the information about the status of the duplexed communication network can be made coincident with the information about other communication stations without the need to take complicated steps.

Fig. 10 is a block diagram of a further example of the communication control device FCA according to the invention. In this embodiment, a means is added which eliminates problems produced when a plurality of token frames that are symbols of authority are present on the communication network HF shared by the



communication control devices. Main components of this means are shown in Fig. 10.

In a token passing communication system, it is assumed that only one of plural communication stations connected with the communication network HF holds a token. However, if the system is again set up after being disturbed by noise, or if the same station address is assigned to two stations for some reason, then the two stations hold the token simultaneously. In this situation, it is impossible to control the communication by normal token passing. The operation of the whole system is affected greatly.

In this embodiment, the means for removing such problems is added. The communication control device FCA of Fig. 10 has a transmission-reception control means 15 which controls the token passing communication and detects errors. A carrier-detecting means 25 receives the signal, for example, on one communication line L1 via a receiver 11 and detects the presence or absence of the carrier from the signal level on the line L1. A collision-detecting means 26 similarly receives the signal on the communication line L1 via the receiver 11. For example, this detecting means 26 monitors the DC component level on the line L1 and has a comparator which detects variations in the signal level caused when the frame delivered from this station is superimposed on the frame delivered from another station.

The communication station of the token-generating means 22 receives the token. When this token is held, the token-generating



means 22 transmits the token to the next communication station under the control of a token control means 24. This control means 24 controls the token-generating means 22 in such a way that when the output signal CD from the carrier-detecting means 25 indicating detection of the carrier or the output signal CLD from the collision-detecting means 26 is received, the token held by the station is abandoned.

Fig. 11 is a flowchart illustrating the operation performed when one communication station having the communication control device of the structure shown in Fig. 10 has obtained the token. The transmission-reception control means 15 usually monitors the token frame transmitted over the communication line L1 or L2. If the token frame is addressed to the communication station of the control means, then it obtains the token (step 11). Then, the carrier-detecting means 25 makes a decision to see if the carrier transmitted over the communication line L1 is received or not, i.e., to see if any other communication station connected with the line L1 is sending the carrier or frame (step 12).

If the carrier is detected, i.e., if the output signal CD from the carrier-detecting means 25 is active, the token control means 24 determines that any other station obtaining the token exists other than the communication station itself. The control means 24 instructs the token-generating means 22 not to generate a token (instructs the token-generating means 22 to abandon the token) (step 13).



If the result of the decision made in step 12 is that no carrier is detected, the transmission-reception control means 15 determines that any other communication station does not have a token, and transmits an acknowledge frame (step 14). One example of the transmitted frame is an acknowledge frame informing the station sending the token that the token has been received. After the transmission of the acknowledge frame, the collision-detecting means 26 monitors the DC signal level on the communication line L1 via the receiver 11 and makes a decision to see if the frame transmitted by the station itself over the line L1 collides with the frame transmitted by any other station (step 15).

If a collision is detected, i.e., if the output signal CLD from the collision-detecting means 26 is active, then the token control means 24 determines that any other station gains the token. The control means 24 instructs the token-generating means 22 not to generate a token, i.e., instructs the token-generating means 22 to abandon the token (step 13).

Thus, a situation in which the communication station itself transmits a frame and, at the same time, any other station transmits a frame is quickly and certainly detected. This situation might not be detected by the carrier-detecting means 25. A serious situation which would be caused by the presence of two tokens can be avoided.

If no collision is detected in step 15, and if there is a request for a given transmission, then this communication



operation and processing of commands are performed (step 16). When the given communication operation ends, or when there is no request for transmission, the token-generating means 22 sends a token frame to the next station (step 17). This transmission of a token is carried out as illustrated in the flowchart of Fig. 8.

If the token is abandoned in step 13, any other station keeps holding the token. The communication is effected under the control of this station.

If a similar collision of frames is detected in any other station and the token is abandoned, then it follows that the token disappears from the communication lines. To allow for this disappearance of the token, the communication control devices of the stations are equipped with their respective token monitor timers which are set at different times. The token-generating means of the communication control device having the monitor timer run out earliest transmits a new token. Therefore, if processing for abandoning the token is performed in step 13, the token passing communication control operation of the whole system is continued normally.

In this embodiment, if two or more communication stations of the token passing communication control system transmit tokens, then the whole system connected with the communication network would be affected. This situation is quickly detected, and then the tokens are abandoned. Hence, a reliable communication control device can be accomplished.

Fig. 12 is a block diagram of a still other example of the communication control device FCA according to the invention. In this embodiment, a failure which affects the whole communication network shared by the communication control devices FCA of the communication stations takes place. A structure is added which detects this failure and prevents the defective communication control device from participating in the communication control operation.

In a token passing control communication system, in order to pass a token smoothly at all times, even if one communication control device getting the token loses the token for some reason (e.g., the power is turned off), the token must be transmitted to other communication control devices. For this purpose, the communication control device FCA of each station is equipped with the carrier-detecting means 25 detecting the carrier on the communication network HF, the carrier monitor timer 27 monitoring the time for which no carrier is detected, and the token-generating means 22 that generates a new token if no carrier is detected for a given time at which the timer 27 is set, i.e., when a signal indicating that the timer 27 has run out is received from the timer.

The preset values at which the monitor timers 27 of the communication control devices are set are made different among the stations. The minimum value of the preset values is so selected that it is larger than the maximum time for which no carrier exists



on the communication network HF during normal operation.

In this configuration, even if the token disappears, the token-generating means 22 included in the communication control device having the monitor timer 27 which runs out earliest generates a token again. In consequence, normal communication control can be continued.

In this equipment constructed as described above, if the receiver 11 or the carrier-detecting means 25 is at fault, the carrier on the communication network HF can no longer be monitored. This communication control device determines that the token has disappeared from the communication network. Whenever the predetermined time at which its own monitor timer 27 is set expires, the device generates a token and send it to the next station, or the next communication control device. This operation is repeated. In this case, if other communication stations are communicating with each other, this communication is impeded.

In this embodiment, to eliminate this problem, a loop back-diagnosing means 28, a counter 29, and a transmission-reception operation-stopping means 30 are provided. The loop back-diagnosing means 28 executes a loop back diagnosis to check if the transmission and reception function of its own communication control device is normal or not. The counter 29 counts a loop back error signal delivered when the loop back diagnosis made by the diagnosing means 28 fails, and produces an error signal when the total count reaches a given value. The stopping means 30 stops the



transmission and reception operation of the transmission-reception control means 15 according to the error signal from the counter 29. An allowable number of loop back operations is previously set into the counter 29.

It is assumed that the receiver 11 of this apparatus is at fault and incapable of reception. Under this condition, the apparatus operates in the manner described now. The carrier on the communication network HF cannot be heard. The output signal CD from the carrier-detecting means 25 is made inactive. The carrier monitor timer 27 counts the time for which the carrier is not heard. When this measured time reaches a preset value, the time-up signal is made inactive. On receiving this time-up signal, the token-generating means 22 determines that the token has disappeared from the communication network HF, and generates a new token. This token is transmitted over the network HF via the transmission-reception control means 15 and via the driver 12, and sent to the next station.

However, a response signal, or an acknowledge signal, to this token cannot be received because of the failure in the receiver 11. Therefore, the transmission-reception control means 15 determines that the transmission of the token is unsuccessful, and repeats the operation for sending the token to the next station. This series of operations is carried out in every communication station connected with the communication network HF, but all trials of token transmission are unsuccessful. During this time interval,



communication between the other stations over the network HF is impeded.

Subsequently, the transmission-reception control means 15 instructs the loop back-diagnosing means 28 to execute a loop back diagnosis, for seeing if the control means 15 itself is at fault. On receiving instructions for execution of the diagnosis, the diagnosing means 28 transmits a communication frame or diagnostic frame addressed to itself over the communication network HF, and carries out the loop back diagnosis to see if the frame can be correctly received. As a result of this diagnosis, the diagnostic frame addressed to itself cannot be received because of the failure in the receiver 11. Therefore, a loop back error signal is produced to the counter 29. On receiving this loop back error signal, the counter 29 is incremented.

If the result of the loop back diagnosis shows normality, i.e., the failure in the receiver 11 is transient and the receiver has recovered from the failure at the time of the loop back diagnosis, then a signal indicating normality is produced. The counter 29 is reset.

The carrier monitor timer 27 runs out whenever the preset value is reached while the receiver 11 is at fault. Therefore, the loop back diagnosing means 28 repeatedly executes the diagnosis. As a result, the value of the counter 29 reaches a given value and produces an error signal.

When the counter 29 produces the error signal, the



transmission-reception operation-stopping means 30 instructs the transmission-reception control means 15 to stop the subsequent operation for transmission and reception. The control means 15 then stops all transmission and reception performed over the communication network HF. The communication control device FCA of the control means 15 is disconnected from the network HF. This operation minimizes the effects on the network even if the receiver 11 or the carrier-detecting means 25 is at fault and the whole system is affected by the failure.

In the description made thus far, it is assumed that the transmission-reception stopping means 30 is incorporated in the communication control device FCA. This stopping means 30 may also be installed in an external device such as the processor unit CPU. In this case, the external device can easily locate the defective communication control device FCA.

In this embodiment, if a failure which would affect the whole token passing control communication system connected with the communication network takes place, only the corresponding communication control device is disconnected from the network HF. Consequently, the communication control devices FCA of the other communication stations can still maintain normal communication. Also, the reliability can be enhanced.

Fig. 13 is a block diagram of a duplexed communication station STi acting as a field control station. This embodiment has a structure which permits each communication station to correctly



diagnose the communication control device FCA of this station.

In the communication station acting as the field control station, arithmetic operations for control are assigned to the processor CPU. A failure in this processor unit leads to stoppage of the process control. Therefore, the communication station is duplexed. If a trouble is detected in the processor unit CPU in each communication station or in the communication control device, the other normal station backs up the defective station.

The general method of diagnosing each processor unit itself is that one CPU diagnoses the other CPU to detect a failure. Each communication control device CA generally adopts a so-called loop back diagnosis, i.e., a communication frame addressed to itself is transmitted and received to see if the transmission and reception function is normal.

Where one processor unit diagnoses the other processor unit to detect a failure, it is difficult to locate which of the processor unit causes an error if such an error occurs. Where each communication control device FCA is diagnosed by loop back diagnosis, if both controlling station and standby station perform their respective loop back diagnoses, then good results would arise. In a token passing communication control system, one station cannot send information unless it obtains a token. Therefore, if the controlling station is at fault, it is impossible to pass the token to the standby station. As a result, the diagnosis in the standby station will be unsuccessful.



In this embodiment, the processor unit and the communication control device are duplexed. The communication control device of the controlling station and the communication control device of the standby station can both correctly make diagnoses to detect failures by loop back diagnosis.

In Fig. 13, two communication stations ST21 and ST22 connected with the communication network HF serve as field control stations. One station such as ST21 is engaged in control, while the other such as ST22 is in standby condition to make preparations for a failure in the one station.

Each processor unit CPU of the two communication stations ST21 and ST22 performs various control operations, arithmetic operations, and gives instructions for loop back diagnoses. The communication control device FCA coupled to the network HF provides the above-described token passing communication control.

The loop back diagnosing means 28 of each communication control device FCA executes a loop back diagnosis under the instructions from the corresponding processor unit CPU. The CPU control means 51 of each CPU produces a ready signal RDY indicating that the control means itself is operating, and produces instructions for loop back diagnosis.

Each of two processor units CPUs has a gate circuit 52 which receives the output signal from the gate circuit of the other processor unit and the ready signal from the corresponding CPU control means 51. The gate circuits of the two processor units



produce selecting signals IOCE1 and IOCE2, respectively, for providing duplex control. These two signals IOCE1 and IOCE2 have a mutually exclusive relation to each other.

This embodiment is characterized in that a counter 53 which is started at the beginning of a loop back diagnosis and reset at the end of the diagnosis is provided. A time-setting means 54 sets a desired time at which the corresponding counter 53 runs out. This set time is made different between the case in which the selecting signal IOCE1 or IOCE2 for duplex control is active and the case in which the signal is inactive. For example, if the selecting signal IOCE1 is active and the token exists in this station, a shorter time is set than the time set when no token exists.

The time-up signal from the counter 53 is applied to the corresponding CPU control means 51. When each CPU control means 51 receives the time-up signal from the corresponding counter, the control means determines that the communication control device FCA of this station is at fault. The control means 51 makes the ready signal RDY delivered from this control means inactive.

Normal operation of this apparatus constructed in this way and operation performed when the communication function is at fault are next described separately.

Operation under normal condition

The gate circuit 52 of each of the two processor units CPUs forms a flip-flop activated by the ready signal RDY delivered from the CPU control means 51. The processor unit CPU in which the



ready signal RDY delivered from the CPU control means 51 is made active earlier renders the selecting signal IOCE1 or IOCE2 for duplex control active, and assumes a controlling condition. Since the two selecting signals IOCE1 and IOCE2 have a mutually exclusive relation to each other, the other station is in a standby condition.

Normally, data bases included in the two processor units CPUs are made coincident with each other by separate means (not shown). Also, these CPUs operate in synchronism. Furthermore, loop back diagnoses are simultaneously started by them.

It is now assumed that the processor unit in the communication station ST21 is in a controlling condition and that the processor unit in the station ST22 is in a standby condition. The time-setting means 54 of the station ST21 knows that this station is in a controlling condition, based on the fact that the selecting signal IOCE1 for duplex control is active. The setting means 54 sets the counter 53 at time T1. The time-setting means 54 of the standby communication station ST22 knows that this station is in a standby condition, based on the fact that the selecting signal IOCE2 for duplex control is inactive. The setting means 54 sets the corresponding counter 53 at time T2. The times T1 and T2 at which the counters are set are so selected that T2 is longer than T1, i.e., the counter in the standby condition is set at a time longer than the time at which the counter in the controlling condition is set.

When the processor unit CPU of the communication station ST21 is in the controlling condition, if the communication control device FCA included in the station ST21 receives a token, the loop back diagnosing means 28 executes a loop back diagnosis. At the same time, the counter 53 begins to count forward.

The results of the execution of the loop back diagnosis are sent to the processor unit CPU. If no error is detected, the counter 53 is reset before the expiration of the set time. Thereafter, the communication control device FCA in the controlling station passes the token to the communication control device FCA in the standby station. Then, the communication control device in the standby station executes a loop back diagnosis similarly.

If the processor unit which is in the controlling condition is at fault for some reason, the ready signal RDY delivered from the CPU control means 51 becomes inactive, inverting the state of the selecting signal IOCE1 or IOCE2 for duplex control. The token is passed to the processor unit in the standby station.

Operation performed when the Communication Function is at fault

The communication control device FCA inside the communication station ST21 in the controlling condition executes the loop back diagnosis, but its acknowledge signal cannot be received. A failure in the diagnosis is repeated. Therefore, the value of the counter 53 in the station ST21 reaches its maximum value when a given time T1 has elapsed. In response to this, the CPU control



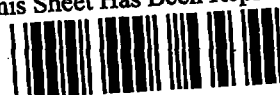
means 51 determines that the communication control device FCA in the communication station ST21 is at fault, and makes the ready signal RDY inactive. Also, the CPU control means 51 makes the selecting signal IOCE1 for duplex control inactive. The token is passed to the processor unit CPU in the standby communication station ST22.

Effects on Standby Station when Controlling Station is at fault

When the communication control device FCA in the communication station ST22 is at fault, or when the driver 12 is at fault, if the fault occurs immediately after the loop back diagnosis, then the diagnosis of the station itself will be successful. However, the token cannot be passed to the communication control device FCA in the standby station ST22. Hence, the loop back diagnosis of this station will be unsuccessful.

However, failure in the next loop back diagnosis is repeated, because the driver in the controlling station is at fault. The time T1 at which the counter 53 in the controlling communication station ST21 is set is longer than the time T2 at which the counter 53 in the standby station ST21 is set. Therefore, the counter in the controlling station runs out earlier than the counter in the standby station. Therefore, if the communication control device in the controlling station is at fault, the token can be passed to the standby communication station ST22 with certainty without being affected by the fault.

The times T1 and T2 at which the timers are set according to



whether they are in controlling state or in standby state are selected, taking account of the times required for loop back diagnoses and the processing time of the CPUs, while maintaining the relation $T1 < T2$.

In this embodiment, each communication station equipped with the communication control device transferring data by token passing is duplexed. Each communication control device can be precisely diagnosed. If any one communication control device is at fault, the token can be passed to a standby station with certainty.

Fig. 14 is a block diagram of a still other example of the communication control device FCA according to the invention. In token passing communication control, the passing of the token is controlled by station addresses assigned to communication stations. When the token is passed to the next communication station, it is customary to send a token frame to the next station having a station address that is equal to the station address of the present station plus one. This token passing is based on the assumption that only one of plural communication stations connected with the communication network holds the token. Therefore, if the same station address is given to two or more stations for some reason, or if the same address is repeatedly used because of a failure in the address-setting means, then the token will be given to two stations. In this case, a collision of token frames occurs on the communication network. It is impossible to



pass the token among all the stations. As a result, the communication is disabled.

In this embodiment, to avoid this undesirable situation, an additional function is given to each communication control device. In particular, when a new station participates in the token passing communication by connecting the station with the communication network or by turning on the power supply, the control device makes a check to see if any address is established doubly.

In the communication control device FCA of Fig. 14, an address-setting means 61 for setting a station address for specifying the communication station of this control device may be mechanical setting means or take the form of computer software. A token-to-itself detecting means 62 detects reception of that token frame from the token transmitted over the network HF and the receiver 12 which indicates the address of this station set by the address-setting means 61. A monitor timer means 63 is set at a predetermined time longer than the sum of the transmission delay time and the response delay time. When the token-to-itself detecting means 62 detects reception of a token addressed to itself, the timer means 63 begins to measure time. A reception decision means 64 makes a decision to see whether frames from other stations are received until the monitor timer means 63 runs out. This reception decision means 64 can consist of a circuit receiving the carrier signal on the communication network HF and a simple logic circuit that detects the reception level.



The reception decision means 64 determines that a double address error has occurred if a frame transmitted from any other communication station is received before the monitor timer means 63 runs out. The decision means 64 produces an error signal to the transmission control means 15. On receiving this error signal, the transmission control means 15 interrupts participation in the communication network HF and abandons the token.

Fig. 15 is a flowchart illustrating the operation when one communication station is connected with the communication network HF. When the power supply is turned on or when a new communication is connected with the network to participate in the communication, the station waits to receive a token frame or an invitation frame (a frame passed through all communication stations which might be connected with the network) transmitted over the network HF via the receiver 12 (step 21). To detect the reception of such a frame, the token-to-itself detecting means 62 compares the station address assigned only to the present station with the station address contained in the token transmitted over the network HF. If the token is addressed to this station, then the detecting means 62 determines that the reception has been made.

If the token-to-itself detecting means 62 receives a token addressed to this station, the monitor timer means 63 is started (step 22). The reception decision means 64 makes a decision to see if any other communication station receives a token and responds to it until the timer means 63 runs out (step 23). If no frame is



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transmitted from other stations when the timer means 63 runs out, i.e., the reception decision means 64 receives neither frame nor carrier transmitted over the network HF, the decision means 64 determines that any other station having the same station address does not exist on the network HF. The operation for monitoring a double address is ended normally (step 24).

Subsequently, the transmission control means 15 transmits a frame over the driver 11 and the communication network HF in response to the reception of the token addressed to this station, and is connected with the network. Thereafter, normal operation can be performed while connected with the network HF.

On the other hand, in step 23, if the reception decision means 64 receives a frame or carrier transmitted over the communication network HF until a given time elapses, i.e., before the monitor timer means 63 runs out, the reception decision means 64 determines that any other communication station having the same station address has already existed on the communication network HF, i.e., the frame is transmitted from this station. The decision means 64 determines that a double address error has taken place and produces an error signal to the transmission control means 15 (step 26).

On receiving this double address error, the transmission control means 15 interrupts transmission of a frame and disconnects itself from the network HF (step 27). In this case, the situation is taken as abnormal address setting, and the operation is ended. A message indicating this abnormality is



delivered.

When a new station participates in communication using the communication network, this configuration permits the equipment to check if the same station address as used by any station connected with the network exists. Therefore, if an address should be erroneously set, the communication will be prevented from being disabled.

Fig. 16 is a block diagram of other embodiment similar to the embodiment of Fig. 14. In this embodiment, if the address-setting means of one communication station of plural communication stations normally participating in communication breaks down, the resulting trouble is removed.

In this embodiment, a multiple-master detecting means 65 detects multiple-master condition, i.e., frames are being transmitted from other stations when the station of the detecting means 65 gains a token and is transmitting a frame in response to the token. That is, a plurality of communication stations acting as masters exist. This multiple-master detecting means is a circuit designed to monitor the signal level of the carrier on the communication network HF and detects a change in the signal level caused by a collision of frames. A collision number count means 66 is incremented when the multiple-master detecting means 65 detects a multiple-master condition. When the total count obtained by the count means 66 reaches a given value, a means 67 giving instructions for stopping participation in the communication



determines that a collision of the address of this station with the address of any other station or other trouble has occurred. Then, the means 67 instructs the communication control means 15 to interrupt the participation in the communication.

Fig. 17 is a time chart illustrating the embodiment of Fig. 16. When some communication station obtains a token, the transmission control means 15 transmits a frame indicating reception of a token addressed to itself (step 31). After transmitting a frame, the multiple-master detecting means 65 monitors the signal level on the communication network HF. The detecting means 65 holds the token and transmits a frame in response to the token. If a frame is transmitted similarly from any other station, and if both frames collide on the network HF, causing a variation in the signal level, then it follows that a multiple-master condition has been detected (step 32). If a multiple-master condition is not detected, the system is regarded as normal, and the operation is continued.

On the other hand, if a multiple-master condition is detected, the count means 66 is incremented (step 33). The means 67 giving instructions for stopping participation in the communication checks if the total value obtained by the count means 66 is excess of a given value (e.g., 3, 4, or so) below which collision due to multiple-master condition is permissible (step 34). If the given value is exceeded, the system is judged to be at fault. The means 67 instructs the transmission control means 15 to interrupt the participation in the communication (step 35). If the total count



does not exceed the given value, the operation is continued as it is.

In this embodiment, during normal operation, if the address-setting means 61 breaks down, and if a collision of transmission due to a multiple-master condition occurs, then the defective station is disconnected from the network when the number of the collisions reaches the given value. Consequently, normal communication can be continued between the remaining communication stations.

In the embodiment of Fig. 16, the monitor timer means 63 and the reception decision means 64 (Fig. 14) for checking a double address when a new station is connected with the bus may be omitted or added.

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WHAT IS CLAIMED IS:

1. A duplex communication control device for transmitting and receiving data among a plurality of communication stations by passing a token among the stations connected with a first communication line and a second communication line, each of the communication stations comprising:

a bus status list storing information indicating whether the station can communicate over the first and second communication lines;

a token-generating means which carries the newest bus status information possessed by the token-generating means itself on a token frame and transmits the token frame;

a list-updating means which receives the token frame transmitted over the first and second communication lines and updates the contents of this bus status list according to the bus status information carried on the token frame; and

a transmission-reception means which selects the two communication lines according to the bus status list and communicates.

2. The duplex communication control device of claim 1, wherein the transmission-reception means selects a predetermined one of the two communication lines and communicates provided that the bus status information contained in the bus status list indicates that both communication lines can be utilized.

3. The duplex communication control device of claim 1,





wherein the transmission-reception means selects the first and second communication lines alternately and communicates provided that the bus status information contained in the bus status list indicates that both communication lines can be utilized.

4. The duplex communication control device of claim 1, wherein each of the communication stations includes a transmission control device providing control of token passing communication by the use of a duplex communication network and a processor unit coupled to the transmission control device via an internal bus, and wherein the transmission control device performs processing of communication independent of the processor unit when the token is passed to this communication station and this or other station ask communication.

5. The duplex communication control device of claim 1, wherein each of the communication stations has a diagnostic token-generating means which carries a diagnostic token on the newest bus status information possessed by this station and transmits the token, the diagnostic token being used to urge a new communication station connected with the two communication lines to participate in communication, and wherein the list-updating means updates the contents of its own bus status list according to the bus status information carried on the diagnostic token frame provided that the diagnostic token is received.

6. A duplex communication control device for transmitting and receiving data among a plurality of communication stations by





passing a token among the stations connected with a common communication network, each of the communication stations comprising:

a carrier-detecting means detecting a carrier on the communication network;

a token frame-generating means which, when the communication station of this token frame-generating means receives a token and the carrier-detecting means detects no carrier for a given time while the token is held by the token frame-generating means, transmits a token frame over the communication network;

a collision-detecting means which, when a frame from any other communication station is received via the communication network after the transmission of the frame, delivers an output signal indicating a collision;

and wherein if the collision-detecting means detects the collision or if the carrier-detecting means detects the carrier within a given time, the communication station abandons the token held by this station and waits to receive.

7. The duplex communication control device of claim 6, wherein the communication stations are equipped with their respective monitor timers which are set at different times, the minimum value of these times being larger than the maximum time for which no carrier exists on the communication lines during normal operation, and wherein if the carrier-detecting means detects no carrier throughout the time at which the monitor timer in the





communication station containing this carrier-detecting means is set, the token frame-generating means determines that the token has disappeared from the communication network and transmits a token frame over the communication network.

8. Communication control devices acting to detect a carrier on a common communication network, to determine that a token has disappeared from the network if no carrier is detected for a given time, and to generate a new token frame, the communication control devices providing a token passing control of communication, each communication control device comprising:

a loop back diagnosing means executing a loop back diagnosis to check if the transmission and reception function of the transmission control device containing this loop back diagnosing means is normal or not;

a counter which, when failure in the loop back operation of the loop back diagnosing means is repeated at given number of times, produces an error signal;

and wherein the transmission and reception operation of this communication control device is stopped according to the error signal from the counter.

9. A duplex communication control device comprising two communication stations, each communication station having a communication control device and a CPU connected with a communication network, the duplex communication control device acting to control the communication stations in such a way that one





station is used as a controlling station and the other is used as a standby station according to two signals which have a mutually exclusive relation to each other for duplex control,

each communication control device comprising a transmission-reception control means controlling token passing transmission of data, and a loop back diagnosing means included in the transmission-reception control means to execute a loop back diagnosis under instructions from the CPU,

the CPU comprising a counter that is started at the beginning of the loop back diagnosis and reset at the end of the loop back diagnosis, and a time-setting means acting to set the counter at different times, depending on whether the station is used as a controlling station or as a standby station,

and wherein when the counter runs out, the communication control device is judged to be at fault and, if this fault occurs in the controlling station, the signals for duplex control are inverted.

10. A communication control device comprising a plurality of communication stations having their respective addresses, the stations being connected via a bus, the communication control device acting to execute communication by passing a token among the stations according to information about the addresses, each communication station comprising:

a token-to-itself detecting means detecting reception of a token addressed to the communication station containing this





token-to-itself detecting means via a communication network;

a monitor timer means which is set at a given time and which, when the reception of the token addressed to this station is detected, begins to measure time;

a reception decision means that makes a decision to see whether a frame from any other communication station is received until the monitor timer means runs out;

and wherein if a frame is received before the monitor timer means runs out, the reception decision means determines that a double address error has taken place, and the station is disconnected from the communication network.

11. A communication control device comprising a plurality of communication stations having their respective addresses, the stations being connected via a bus, the communication control device acting to execute communication by passing a token among the stations according to information about the addresses, each communication station comprising:

a token-to-itself detecting means detecting reception of a token addressed to the communication station containing this token-to-itself detecting means via a communication network;

a multiple-master detecting means which, if the token-to-itself detecting means receives a token addressed to itself, transmits a frame and then detects a collision of frames on the communication network to detect a multiple-master condition; and

a collision number count means which counts the number of



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repetition of detection of the multiple-master condition and which, when the value of the collision number count means reaches a given value, instructs the station to disconnect itself from the communication network.

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