The Application and Practice of Condition-Based Maintenance in the Space Launch Site

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Abstract: According to the advanced concept of the Condition Based Maintenance (CBM) equipment at home and abroad, this paper has combined with own experiences, analyzed the equipment Condition Based Maintenance (CBM) which is based on the implementation of management system, the quality of the staff and the technique, introduced the flow and the results of the Condition-Based Maintenance (CBM) work and pointed out its feasibility of the reality and wide prospects of the development.

Key words: Space Launch Site, Equipment, Condition Based Maintenance (CBM)

Introduction

The maintenance strategy at home and aboard mainly have underwent three stages during the developing history of management of equipment maintenance: Corrective Maintenance (CM) → Time Based Maintenance(TBM)→Condition Based Maintenance(CBM). CM is the equipment's checking and repairing after the accident or the damage happening on it. TBM is to master the equipment's failure rate and average life expectancy according to the past experiences, regulations and the use of equipment so as to determine the size and interval of equipment's maintenance. CBM is based on the state information provided by advanced condition monitoring and diagnostics technique to judge the abnormal condition of equipment and to predict equipment failure, which is the way of maintenance before failure occurred, that is, according to the state of normal operation to arrange the plan of maintenance to implement the equipment maintenance. The industry standard of the cost of using three methods to maintenance is: the cost of CM=3×the cost of TBM=9×the cost of CBM.

China Jiuquan Satellite Launch Center (referred to as the Center) started the exploration and practice of the CBM from 2000. In 2003 Center set up the organization of the CBM, equipped with advanced detecting instrument, developed and researched technology-related, implemented the CBM to equipment that depend on the management system, the staff's quality and the technique. By continuing to explore, practice and improve working procedures, the CBM was impelled in an orderly way and achieved its desired effect, created a unique CBM management.

I. The key of the implementation of the CBM is the system management

CBM is a complex of high-tech project, which involves the management mode, the monitoring technology, the diagnostic techniques, the assessment technology, the economic analysis, the quality of staff and other aspects. And the core is to establish a set of appropriate maintenance management system to ensure the implementation of advanced maintenance strategy to achieve the operation of equipment and maintenance of a full range of modern management.

I.1 Drawing up the "three-step" development goal of the CBM

To determine the direction of development of the CBM and strengthen the overall planning, equipment maintenance center in accordance with the actual development of the system, in 2003 the center made clearly the "overall planning, step-by-step implementation, the first pilot, steady progress" in principle, drew up the

CBM "three-step "development goals: The first step which was beginning in 2003, established and improved the organizations of the CBM ,the related system and the standard of work in order to implement the management of the maintenance which combined TBM and CBM. The emphasis of this step was focused on the application and analysis of the technique of CBM equipment; Second, Center lasted advancing the CBM, according to the type of equipment, the importance, the state of normal operation and the state of failure to classify equipments and to choose some of equipments to carry out pilot projects of the CBM; the third step, from the beginning of 2005 the work is all-round deepening the CBM. It will be extended to all of the equipment, and further enriched and improved the means of detection and management of tools in order to form a unique pattern of the management of equipment maintenance.

I.2 The establishment of the CBM organization and detection network

Center established the Three-tier organizations and two-stage detection network about the CBM by the method of which combined centralized control and management at different levels to enhance the organization and leadership of the CBM. Three-layer organizations include policy-layer, management-layer and operation-layer. Policy-layer that is constituted by the competent leadership of the Equipment and three groups of technical expert is in charge of the management and planning of the CBM to make the decision of the maintenance and assess the result of the implementation; Management-layer that includes two Diagnostic Testing Centers is specific in charge of getting the information of equipments' condition, and then to put forward maintenance's proposals after which being analyzed and evaluated in order to drawing up or censoring out the maintenance's plan, technology and so on. It is also in charge of supervising the implementation and checking before acceptance of the maintenance. Operation-layer that is the maintenance group is in charge of the CBM, maintenance and repair, formulating the specific implementation plans of Maintenance's projects and being responsible for the quality of projects. Two-stage detection network contains the Diagnostic Testing Center and the maintenance group, which respectively are responsible for monitoring equipment's dynamic information (operational information) and detecting static information (conventional test).

I.3 Drawing up the management institution and the technical standards about the CBM

The CBM on equipment is a system engineering which is more scientific and rigorous than the traditional TBM management, which needs to be supported by completely institution. For this reason, center drew up the administrative measures of CBM, the control program of CBM, the implementing regulations of CBM, the administrative measures of condition diagnosis and totally 22 management systems. And it also worked out the guidebook of standardized operation of the CBM on equipment, the condition diagnostic standards, the assessment and classification of equipment condition, the maintenance strategy, the equipment repair with technical standards, such as 58 technical standards. According to the need of the center developing, the rules, regulations and technology standard were amended in time so as to providing a reliable guarantee for implement CBM system.

I.4 The configuration of the advanced detection and monitoring equipments

The basis of the CBM information is comprehensive and systemic data about condition monitoring. The presupposition of CBM is whether or not to master real-time equipment conditions with the advanced detection technique previously, to identify the properties of the defects and the order of severity.

As a result, the Center attached great importance to construct testing manner so as to configuring a large number of detection equipment. For example, the Test and Diagnose Center of Power Equipment State has

configured insulated electrical equipment testing device, electrical characteristics testing device, Structure characteristics testing device, infrared monitoring device, and fault diagnosis device, in total 108 devices. In the on-site, power quality monitoring system, the vibration of the unit monitoring system such as on-line monitoring devices was installed.

II. the principal task for the implementation of the CBM is to improve the staff's quality

In the CBM practice, we deeply recognize that it's not enough to only use technology as the only law of maintenance decision-making. It's because not only the technology that is not mature and doesn't satisfy our needs, but also some economic reasons. It isn't and shouldn't only depend on technology regardless of economic factors. To resolve this matter and make the maintenance decision-making to meet our practical needs, technologies should be improved; the power of labor force should be played; the management manner should be more effectively taken.

II.1 convert the concept and understand the real meaning of the CBM

One of the difficulties faced in the implement of the CBM is that a part of staff don't understand much about the exact meanings and the technical actuality of the CBM, expect too high about the CBM and will doubt the CBM if they don't have the effect in the short term. Thus, the real meaning of the CBM should be correctly understood to promote the CBM at this stage. In theory, the CBM is in a higher level than planned maintenance. The CBM is a maintenance method that advanced state monitor technique can be utilized; distinguish early symptom; judge the position, severity and trend of malfunctions; arrange the maintenance time and project according to the results of analysis and diagnosis. However, in the aspect of technique, it's impossible to implement the CBM in all devices. Particularly some large-scale equipment, it's rather difficult and risky to diagnose the device states and make the maintenance plan according to the change of one or two parameters, and already existing technology can't meet the need of all devices. Furthermore, the fundamental difference between the CBM and time based maintenance is that: the former is based on the real working status of devices, and the latter is based on the operation time of the device. Thus, it's not perfect to only use the concept the CBM to describe the reform of maintenance technique and plan; it's impossible to have a directly using and unified criterion; the CBM should be considered as a comprehensive maintenance method which we can take different manners, such as predictive maintenance, time based maintenance, correction maintenance and active maintenance, according to different device states.

II.2 Strengthening training and improving the overall quality of staff

The basis of existence and development of enterprise is the talents, high quality production staff is the key of the CBM to success. the TBM need the productive technicians skilled in the face of one kind of professional knowledge shortly is big difference between the CBM and the TBM in the quality of requirements of staff, while the CBM need Multi-skill-based technicians who have comprehensive expertise, independent judgment. The staff should have lofty technology of maintenance and strong capability to deal with the accident in order to being able to master the technique of the CBM and the fault analysis, evaluate the normal status of equipment synthetically, and participate in decision-making of maintenance. Therefore, it not only need to train related staff at different levels, increase the knowledge levels of the CBM, also training of diversified and all levels should be progressed endlessly, and that the task of CBM can be continued to pursue permanently

and normally.

The first phase of the train focuses on the managers. The leader's attention and sustain is the key to success and the CBM is a first-chair project, no matter the scope of influence and the influence to the corporation. Only if the managers support the CBM and spread the idea of maintenance, the project can be developed effectively and the coordination during implement can be guaranteed. The second phase focuses on the general staff. People in all respects should take part in the CBM. Thus, making every staff change their concept and understand their responsibilities and functions can build a wide range of supported base to help the success of state maintenances. The third phase focuses on technicians. The technicians' passion and master degree of maintenance knowledge is one of the key factors to make sure the success of maintenance. The training should stress on the basic concept and implement process of maintenance, especially the use of technology. Through the training technicians can master methods of state maintenance and clearly understand the aims and requests of their work.

III. The necessary condition for the implementation of the CBM is to master the latest technique

The in-depth study of basic theories and laws can improve the technologist practices. Scientific equipment state evaluation system and practical malfunction diagnosis model may be established only by strengthening the research of basic theories, especially the research of equipment diagnosis theory and method, the acquaintance of the operation rules and the dynamic of devices, the malfunction mechanism and the development process of devices, the internal relations of malfunction features and the malfunction model. There are mainly 4 aspects of the theories and technologies that relate to the CBM and can directly improve the quality of the CBM.

III.1 The reliability of devices

Reliability analysis is one important process of the CBM. Weak link, key parts, measures to be taken of devices and systems can be determined through reliability analysis. Meantime, we can determine some possible potential failure of the object, reveal all kinds of failure models and its internal relation, guide the establishment of failure diagnosis and maintenance project, determine the optimum configuration of systemic detective device. Different devices, whose importance also differs, may be used different maintenance strategy according to the results of reliability analysis. Equipments which we need to be high reliable should be adopted the maintenance strategy which includes high request of detective project, precision and frequency. Equipments which we don't need to be high reliability should be adopted the maintenance strategy which after malfunction maintenance is much more economical than the CBM. For equipments whose reliability is low or which have little influence on the function of system, the most reasonable and economical method is to replace them when they don't work. The main jobs of reliability analysis are as follows: making sure functions of systems and devices analyzed; analyzing function malfunction model and its results; finding methods to handle with the malfunction and choosing the suitable method of maintenance; putting the maintenance into practice, assessing and improving.

III.2 Life management of devices and forecasting technique

Life evaluative technique is also one important process of the CBM. To determine the maintenance interval

is directly related to the loss life of equipments. In the past work of equipment management, at first maintenance is commonly estimated based on experience. Through a long period of information accumulation, its life can be accurate estimated so that maintenance can be accomplished in the most appropriate time. Nowadays, with the development of computer technique, it's rather useful to estimate the life loss through numerical experiment and digital simulation, in particular the devices which we can't use full-scale experiment or can't do the life exploration. To research the life issue, maintenance can be implemented though the following three aspects: firstly, make sure the improvement, the maintenance direction of key equipments and systems; secondly, make sure the maintenance item, maintenance internal and maintenance guidelines; thirdly, propose the optimum cycle of replacing equipment parts.

III.3 Device state monitor and failure diagnosis technique

Devices monitor and diagnosis is the core of the CBM. The basis of on-line diagnosis and off-line analysis is state monitor .Equipment diagnosis on general is consisted of static diagnosis and dynamic diagnosis. Static diagnosis is to master the state of equipments through routine or off-line exploration; dynamic diagnosis is to master performance and normal state of equipments. The objective of both static diagnosis and dynamic diagnosis is to provide foundation of the maintenance decision-making. Modern testing apparatus and computer system and software are used to state monitor and malfunction diagnosis, which include monitoring equipment state and abnormal cases, analyzing and forecasting the trend of state to change, diagnosing, identifying malfunction and its reasons.

III.4 Information management and maintenance decision-making technique

We must accurate numbers, which can describe the state of equipments, to put the CBM into practice. That is, we need plenty of availability information to analyze and make a decision. That refers to integrated management of state numbers. The concept of modern data integrated management is the combination of data-base and analysis system. The bases of the CBM data management is a series of data-bases including the reports of the running, data of production, maintenance history, equipment state monitor and diagnosis data, equipment performance data and so on. Maintenance decision-making is: analyze and diagnose equipment state information; hold the state of equipments on general, keep an eye on keeping important functions of system; through malfunction model, results and importance analysis, estimate the life of equipments and the risk rate of the malfunction of equipments; seek the balance between reliability and the cost of maintenance; finally choose a maintenance manner and make a maintenance plan. Maintenance manners can't be the same. Some devices don't need state maintenance at all, and states of some devices can't be monitored and diagnosed in time using existing technique. Appropriate maintenance should be chosen according to the importance of the equipments, type of the failure, the request of diagnosability and reliability and technical economy comparison.

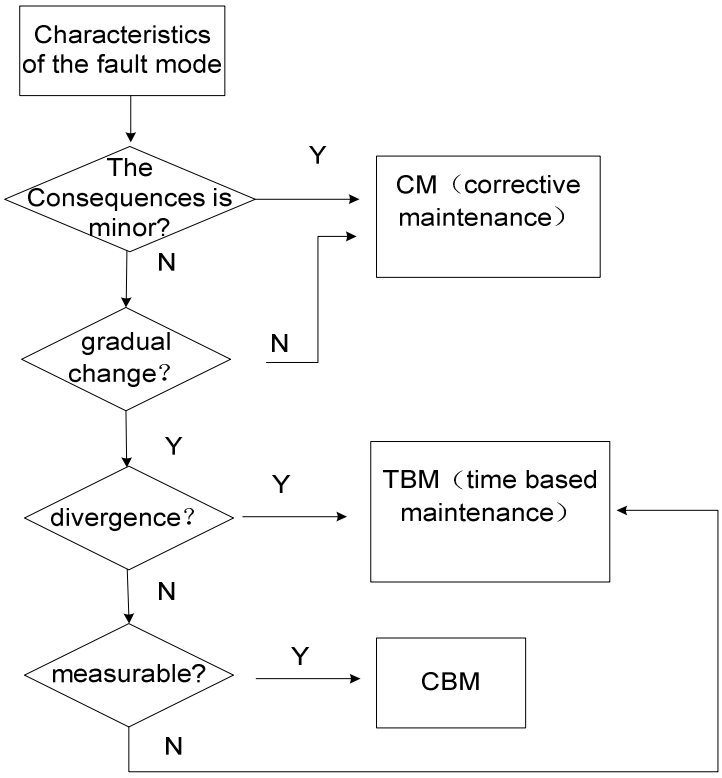

Fig.1.selection principles of the equipment's maintenance manner

IV. The Working flow of the CBM of the Space Launch Site's equipments

Fig.2. is the diagram of CBM management system of the Space Launch Site. Through evaluating the main workflow can get the condition of equipment condition, the maintenance way and the detection/monitoring tools to determine the goals of maintenance; making sure the various equipment maintenance manners by using the analysis of reliability-centered; monitoring the equipment and acquiring the information of the equipment condition, according to the need for rational distribution of monitoring and diagnosis system; Putting forward proposals in the maintenance by analyzing the equipment condition comprehensively; Making decision in the maintenance and arranging the maintenance work reasonably according to the equipments condition and the actual needs; and then drawing up a series of systems to estimate the results of maintenance, improving and perfecting the management and maintenance manners constantly, after which a closed-loop system was built up. We focused on the following works in the implementation process.

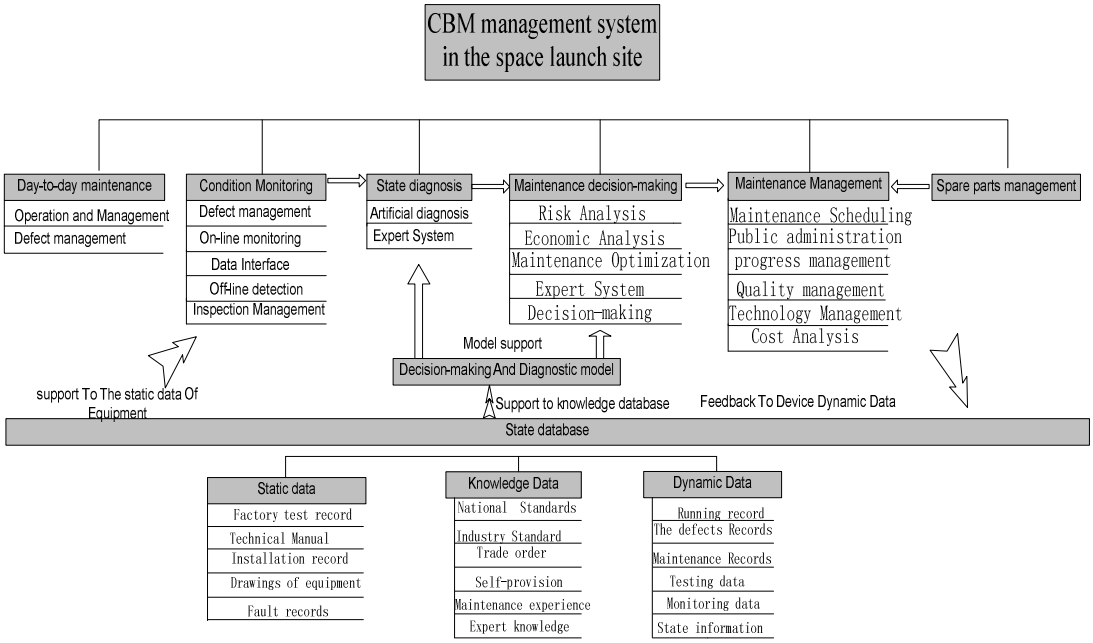

Fig.2. the diagram of CBM management system of the space launch site

IV.1 Controlling the initial equipment condition well and strengthening the management basic information

The CBM is based on the equipment basic management. If there aren't these basic management such as original records, equipment account, order system, drawing and technical information, operation analysis, the equipment can not be supervised very well and the implementation of the CBM that is inane talk. In other words, the CBM is not a simple maintenance aspect of the work, but is that its various links in the life cycle of equipment must be concerned throughout the whole processes of management. Therefore, we should make sure the initial equipment condition is under control, which includes plan, equipment selection, equipment supervision, factory inspection, installation, commissioning and other aspects of the work .What's more, the original records of equipment, equipment account, drawings, technical information and experimental data about the operation, maintenance are also should be processed and collected carefully to get "fingerprint" of information as more as possible.

IV.2 Launching the CBM comprehensively and mastering the information of equipment's operation

(1) The static testing of equipment state is to determine and to detect its condition and function after the equipment outage. The testing plan in line with the CBM strategy should be developed based on enhancing the comprehensive analysis of historical condition: the frequency of testing should be increased for a small number of equipments in poor condition; if necessary, the track testing should be taken for some equipments with serious shortcomings; the test cycle can be broadened for most equipments in good condition.

(2) The dynamic testing of equipment state is to detect and monitor the online equipment's operation condition. One side, we should organize "Six Fixed" (Fixed object, Fixed parameters, Fixed points, Fixed equipment, Fixed cycle, Fixed staff) detection with the help of Infrared thermal imaging device and vibrancy spectrum. On the other hand, it makes use of on-line power quality monitoring and on-line vibration

monitoring system to monitor real-time equipment operation.

(3) The diagnosis of the senses is attached attention to. The detection technique are increasingly instrumentation and intelligent. However, with sharp eyes, ears, nose and smell, touch the senses of diagnosis, and with its simple, intuitive and mass characteristics of the equipment still play important role in the inspection and maintenance that is an important manner and effective supplementary for us to carry out the CBM.

IV.3 Putting forward maintenance proposal according to comprehensive analysis of diagnosis

Maintenance teams and groups carry out the anomaly analysis, trend analysis of associated equipment, and submit the report of the state of equipment and the maintenance proposals; Diagnostic Testing Center gathers various types of status messages, puts up comprehensive analysis and bring forward a comprehensive report and maintenance proposals on the status of equipment; the leader in charge of equipment and the group of technologist carry through the analysis of the decision-making. Primarily comprehensive analysis is on the basis of the experience, regulations, standards, the law of equipment failure, reliability analysis, and so on. Through analysis of the state of equipment, we can carry out a comprehensive analysis and assessment. □we diagnose potential failure of the equipment, analyze the mechanism of failure and the potential risks, estimate the cost of repair and maintenance, and advance overhaul proposal and preventive measures according to the importance of the recommendations. □we also predict the trend on the state of equipment, lodge overhaul proposal or maintenance proposal for the fixture which presented the trend of deterioration.

IV.4 Evaluating the effect of maintenance, implementing the closed-loop management

Through the way of holding meetings about the CBM regularly, we evaluate the implementation of each maintenance project. Aiming at the problems found in maintenance and the results, we should survey again whether the way of maintenance is right, whether the detection technology and maintenance frequency is reasonable, whether the state's analysis of diagnosis is right, whether the correlative management system and operating instructions is possible? If there are any questions, we must adjustment the original criteria state, monitoring means and frequency, and the way of maintenance.

IV.5 Enhancing the research of diagnostic technology, optimizing the CBM unceasingly

With the gradual implementation of the CBM, there is a question about criteria for failure, which is a criterion for re-validation. This is the inherent requirement of CBM, is also an urgent issue need to resolve. Thereby, according to the actual needs, we re-consider a variety of the original order's validity and reliability, add the void critical item in the regulations, and preserve validity of the CBM through revising and improving technical standards constantly.

V. The implementation effect of the CBM

The CBM of equipments in the space launch site runs through "two main lines"(on-line state monitoring、offline state detection), by holding "one conference"(the analysis conference on the CBM date), for comparing the two analysis(the historical vertical compare and the similar horizontal compare), so as to form "a curve"(equipment normal curve). According to it the equipment state can be divided into three types: normal, suspicion, failure. According to the result of the quantitative detection, it can carry out the CBM in a targeted

manner which improves the equipment's reliability and economy in order to make sure the equipment run securely and steadily.

V.1 A substantial increase in equipment reliability, but the rate of the failure decrease year by year

Through the CBM, a number of major equipment problems are identified and eliminated timely which improves the normal level of the equipment. Available coefficient of the equipment rises from initial 82% to 98% now .The forced outage rate drops from 0.15%to below 0.05% and the number of major equipment unplanned outage does not exceed 1 / (year. machine).At the same time, there is a substantial reduction in equipment failures. For example, the power supply equipment emergency failure happened more than 3 times every year before 2003, but since 2005 only one has happened; the power line fault outage rate was 5.06 times every 100/km and the outage coefficient was 1.1 hours in 2003, which fell to 0.42 times and 0.18 hours respectively in 2007.

V.2 Extending the equipment maintenance cycle, maintenance cost is reduced significantly

By optimizing the process of the equipment maintenance, the maintenance plan can be strengthened and the duration of maintenance can be shortened which result in the extending of equipment maintenance interval and avoid excessive maintenance of the equipment or lack of maintenance. It can achieve a reasonable balance of labor resources and the use of man-hours, materials, controllable costs which can lower the cost of maintenance. For example, the maintenance period of the Turbine generator set can be shortened from 40 to 50 days before to the current 20 days or so; the overhaul interval cuts down from one time every 4 years before to the current 6 times a year, and the minor repairs interval extends from one times a year before to one times every two years now.

V.3 The maintenance workload is decreased, but the CBM is promoted to a benign circle

Through state detection and fault diagnosis, the overhaul plan can be transited to the CBM which reduces the number and the time of maintenance so that the maintenance work can be shortened more than one-third contrast to the past but maintenance efficiency is improved by 40%. Maintenance staff can break away from the heavy maintenance work so that the staff can spend lots of time in state detection in order to further promote the development of the CBM.

V.4 The safety of body and equipment is provided with better security can be guaranteed

With the CBM, a large number of equipment outage maintenance and the workload of defects are reduced and the probability of the occurrence of physical accident is decreased. For example, the original plan time to overhaul is relatively intensive and there are lots of transmission and distribution equipments, power distribution lines in the power supply system which make the number of power off nimiety and sometimes even blackout maintenance happens every day that results in personnel fatigue. In practical work, personal accident occurs in the system from time to time. The CBM reduces the frequency of power failure and the operation of equipment so that the chance of disoperation can be decrease which is benefit for ensuring personal safety and equipment security.

V.5 Improvement of staff' skills

Technical and practice knowledge has been centralize and practicability after carrying out the CBM, the decision-making of the maintenance has become clear and verifiable. It largely improves the technicians', especially the young technicians' level. For example, the accurate diagnosis ability of equipment fault is strong, the precision of buried power cable' diagnosis location has been to one meter and the infrared detection rate of equipment's radiation failure rate has been to 100%.

VI. CONCLUSION

The practice proves that the CBM is indeed a good mean and road in enhancing and improving the examining, repair and management of the equipment. It is provided with hearty vitality. The CBM is also a dynamic, mending and closed-loop operation systems engineering, it is a practice - understanding - and then practice – rethink process which rises spirally. At present, whether in the improving of management strategy, or the integrity of operational mechanism, we still need to practice repeatedly and improve continuously, to promote the development of the CBM into a deeper level.

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