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Prediction of Wide and Narrow Seam Deformation of CRTSII track slab by SARIMA Model

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Abstract : ***The wide and narrow seam deformation of the CRTSII type track slab will directly affect the safety of the train operation. Aiming at the complex factors and low detection efficiency of the wide and narrow seam deformation of CRTSII type track slab, this paper proposes a new method based on seasonal ARIMA model for the analysis and prediction of wide and narrow seam deformation through monitoring data of track slab dedicated line in East China. The conclusion shows that: the seasonal ARIMA predict the deformation trend of the CRTSII type track slab with high prediction accuracy.***

Keywords: CRTSII Track Slab; Wide and Narrow Seam; Deformation; SARIMA Model; Prediction; Accuracy

Introduction

In recent years, with the increase of service time of the ballastless track, repeated effects of temperature load and train load make the deformation of wide and narrow seam increase, which seriously threatens the operational safety of track slab. Therefore, monitoring of the deformation of ballastless track slab becomes very meaningful. However, due to the influence of various factors, such as vehicle load, temperature, humidity, self-load and self-structural change (degeneration), the deformation of the wide and narrow seam of the track slab is generally complicated. It exhibits not only certain periodicity and trend, but random fluctuation characteristics, so it is difficult to conduct an overall analysis[Ⅰ].

The basic idea of the ARIMA (Autoregressive Move Average) model proposed by Box and Jenkins[Ⅱ] is to eliminate the trend term in the sequence and convert the non-stationary sequence into a stationary sequence. This method has been widely used in data analysis and forecasting in engineering building deformation[Ⅲ]. However, this stationary sequence does not take the seasonal factors into account. Through analysis of the monitoring data in the CRTS Ⅱ type track slab from east China, it is easy to find the data of deformation with periodic and trending characteristics. In this case, based on the classical time series model of ARIMA, this paper arises a new SARIMA method for analyzing and forecasting the deformation of the wide and narrow seam. By comparing and analyzing the prediction results, it is proved that the model can highly reflect the trend and periodicity of the observation sequence and has high prediction accuracy.

SARIMA model introduction

1.1 The construction of product seasonal model based on ARIMA

The ARIMA model also called (p, d, q) model[Ⅳ], which consists of three parameters p, q and d, where d is the difference term that to the model become smooth. Than the ARIMA model becomes the ARMA model after d-order difference, which consists of autoregressive feature polynomial Φp(L) and moving average operator Θq(L) [Ⅴ]. The seasonal ARIMA model refers to a certain characteristic that repeats at a fixed time interval[Ⅵ]. Compared with the ARIMA model, the seasonal ARIMA model is suitable for modeling non-stationary time series with both periodicity and trend, including all sequences with periodic changes (quarters, monthly and weekly, and so on). Its mathematical expression is ARIMA (p, d, q) × (P, D, Q) s. The model extracts the periodic correlation with ARIMA (p, d, q), and fits the time series with the product combined with the two models, so it is also called the product seasonal model[Ⅶ]. The expression is as follows:

$$\Delta^{d}\Delta^{D}{}_{S}x_{t}\frac{\Theta(L)\Theta s(L)}{\Phi(L)\Phi s(L)} = u_{t} \quad (4)$$

In the formula: S is the seasonal cycle step size and D is the seasonal difference order，

$\Delta^{D}{}_{S} = (1 - L_{S})^{d}$.

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$$\Phi_S(L) = 1 - \varphi_1 L_S - \varphi_2 L^{2S} - \dots - \varphi_P L^{PS}$$
$$\Theta_S(L) = 1 - \theta_1 L^S - \theta_2 L^{2S} - \dots - \theta_Q L^{QS} \quad (5)$$

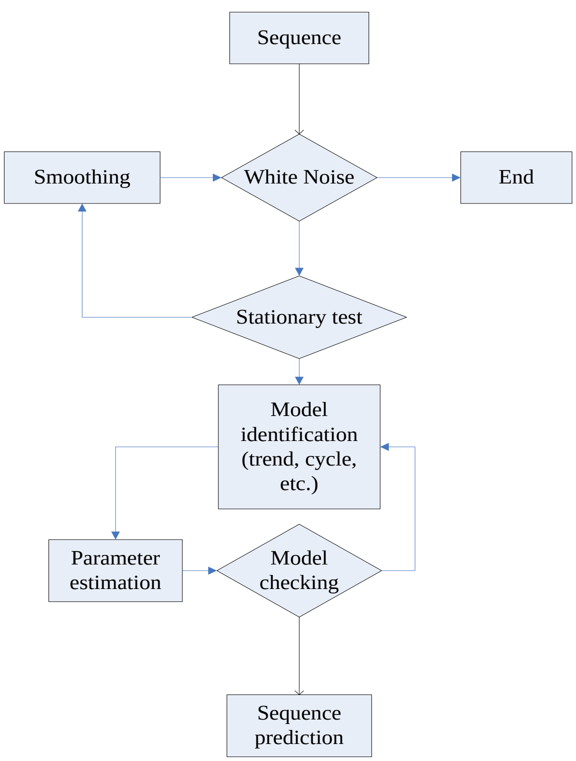
ΦS (L) and ΘS (L) are called seasonal characteristic polynomial and seasonal autoregressive operator, respectively; P and Q are the maximum lag order of seasonal autoregressive feature polynomial and moving average operator, respectively.

1.3 General steps to establish SARIMA Mode

In the process of implementing the SARIMA model, there are several steps generally to consider.

1) The time series after the difference operation should be determined by the stationarity test (ADF [Ⅷ] unit root test method) and the non-white noise test.
2) Determine the order of the model according to the minimum criteria of the AIC and SC [Ⅸ].
3) A white noise test should be performed on the model residuals (using the Ljung_Box test statistic) to establish ARIMA(p,d,q) × (P, D, Q) s product season model [Ⅹ].

1.4 Modeling and forecasting process



Picture 1 SARIMA modeling flow chart

2. Engineering case analysis

In order to verify the prediction efficiency of the ARIMA product season model, wide and narrow seam deformation of a CRTSII type track slab in East China was monitored for 3 weeks at intervals of 30 minutes(Figure1), and then use the data for analysis, modeling and prediction.

2016.9.21—2016.10.11					
Time Point	**Wide seam**	**Narrow seam**	**Time Point**	**Wide seam**	**Narrow seam**
1	0.09	0	…	…	…
2	0.11	0	995	0.06	0.02
3	0.12	0.01	996	0.08	0.03
4	0.13	0	997	0.1	0.02
5	0.15	0.01	998	0.12	0.02
6	0.15	0	999	0.15	0.03
7	0.16	0	1000	0.16	0.03
8	0.16	0	1001	0.16	0.03
9	0.16	0.01	1002	0.17	0.03
10	0.16	0.01	1003	0.18	0.03

Figure 1 Wide and narrow seam

2.1 CRTSII type track slab wide and narrow seam deformation data preprocessing

According to the monitoring data obtained in Table 1, the timing chart of the wide and narrow seam deformation of the CRTSII type track slab is drawn, as shown in Fig.2 (2a wide seam, 2b narrow seam). As shown in Figure 2, $\{X_t\}$, $\{Y_t\}$ present significant seasonal and trending characteristics. Considering that the measurement interval of the wide and narrow seam of the CRTSII type track slab is 30 minutes. And CRTSII type track slab is affected by the cyclical changes of train flow, temperature and exhibits a cyclical change in days. Therefore, the step size of the SARIMA seasonal cycle is initially determined to be 48.

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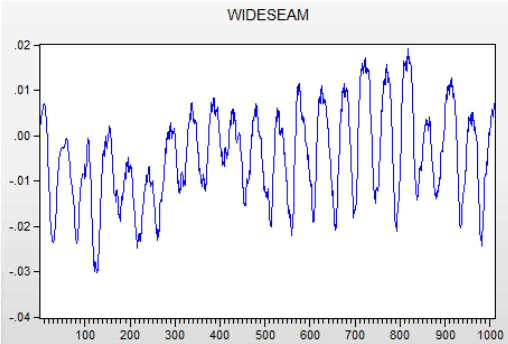
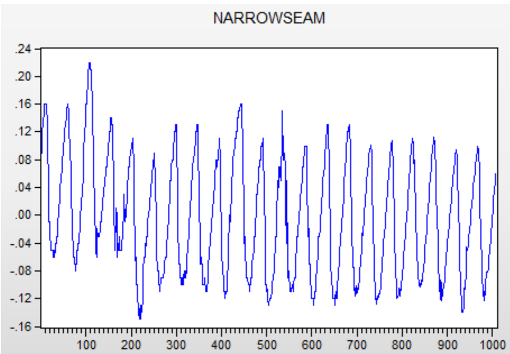


Picture2aWideSeamDeformation



Picture 2b Narrow Seam Deformation

1) It can be seen from the images that the wide and narrow seam deformation contains both a trend term and a period term, which is obviously not white noise. {Xt}, {Yt} for first-order trend difference and first-order seasonal difference (step size 48), get the sequence { DXt}, {DYt}.

2) Perform the stationarity test on {DXt}, {DYt} using the ADF unit root test method. The T statistic values were 0.001, 0.0000 (Fig. 3a, 3b), which were much smaller than the critical values at the significance levels of 0.01, 0.05 and 0.1, so the sequence {DXt}, {DYt} passed the stationarity test.

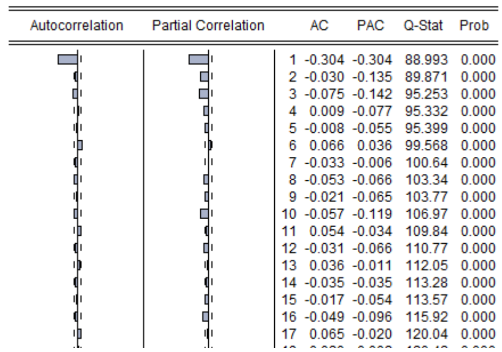
		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-24.20145	0.0000
Test critical values:	1% level	-3.436969	
	5% level	-2.864351	
	10% level	-2.568319	

3a Wide seam stability test

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-44.50674	0.0001
Test critical values:	1% level	-3.434689	
	5% level	-2.863344	
	10% level	-2.567779	

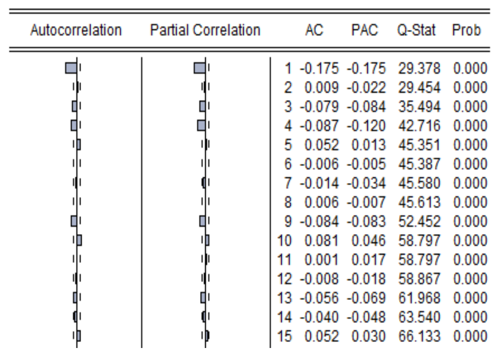
3b narrow seam stability test

3) Differentiate the sequence {X_t}, {Y_t} by d=1, D=1, and S=48 to obtain the sequence {DX_t}, {DY_t}. Through the autocorrelation function (ACF) of{DX_t}, {DY_t}and the partial autocorrelation function (PACF)) (as shown in Figures 4a, 4b), it can be seen that the images ACF and PACF after the difference are both converged. It means that the parameters: d=1 and D=1, S=48 is selected correctly, so the ARMA model can be established.



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.304	-0.304	88.993	0.000
		2	-0.030	-0.135	89.871	0.000
		3	-0.075	-0.142	95.253	0.000
		4	0.009	-0.077	95.332	0.000
		5	-0.008	-0.055	95.399	0.000
		6	0.066	0.036	99.568	0.000
		7	-0.033	-0.006	100.64	0.000
		8	-0.053	-0.066	103.34	0.000
		9	-0.021	-0.065	103.77	0.000
		10	-0.057	-0.119	106.97	0.000
		11	0.054	-0.034	109.84	0.000
		12	-0.031	-0.066	110.77	0.000
		13	0.036	-0.011	112.05	0.000
		14	-0.035	-0.035	113.28	0.000
		15	-0.017	-0.054	113.57	0.000
		16	-0.049	-0.096	115.92	0.000
		17	0.065	-0.020	120.04	0.000

Picture 4a Wide seam difference



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	-0.175	-0.175	29.378	0.000
		2	0.009	-0.022	29.454	0.000
		3	-0.079	-0.084	35.494	0.000
		4	-0.087	-0.120	42.716	0.000
		5	0.052	0.013	45.351	0.000
		6	-0.006	-0.005	45.387	0.000
		7	-0.014	-0.034	45.580	0.000
		8	0.006	-0.007	45.613	0.000
		9	-0.084	-0.083	52.452	0.000
		10	0.081	0.046	58.797	0.000
		11	0.001	0.017	58.797	0.000
		12	-0.008	-0.018	58.867	0.000
		13	-0.056	-0.069	61.968	0.000
		14	-0.040	-0.048	63.540	0.000
		15	0.052	0.030	66.133	0.000

Picture 4b Narrow seam difference

In summary, the ARIMA (p, 1, q) × (P, 1, Q) $_{48}$ model can be established for the CRTS II type ballastless track slab across the wide and narrow seam deformation sequence.

2.2 Determining the model order

Both the sequences {DXt} and {DYt} are stationary. The autocorrelation coefficient and the partial autocorrelation coefficient of the sequence {DXt} are both trailing from the wide seam ACF diagram of Fig. 4a, and it can be determined that p=1, q = 1 or 2, P = 0 or 1, Q = 0 or 1. For the preliminary analysis of the six model list analysis, as shown in Figure 2, the ATC and SC size values are tested, and the calculated goodness statistics of each model are shown in Table 2.

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Models	AIC	SC
ARIMA(1, 1, 1) × (1, 1, 1)48	9.3604	9.2602
ARIMA(1, 1, 2) × (1, 1, 1)48	9.383	9.283
ARIMA(1, 1, 1) × (0, 1, 1) 48	10.364	9.402
ARIMA(1, 1, 1) × (1, 1, 0) 48	15.232	14.335
ARIMA(1, 1, 2) × (0, 1, 1) 48	9.356	9.266
ARIMA(1, 1, 2) × (1, 1, 0) 48	13.331	12.223

Figure 2 Wide seam model fitting statistics table

In Table 2, the AIC and BC values of the ARIMA(1,1,1) × $(1,1,1)_{48}$ model is smaller, and the model is compared to ARIMA(1,1,2) × $(1,1,1)_{48}$ simplifier, so it can be determined as the final model.

After making differences in the deformation of the narrow seam of the track slab, it is easy to find from the figure that the autocorrelation and partial autocorrelation are both 1, and p=1, q=1, P=1 or 0; Q=1 or 0, so there are mainly 3 Models to analysis, as shown Figure 3

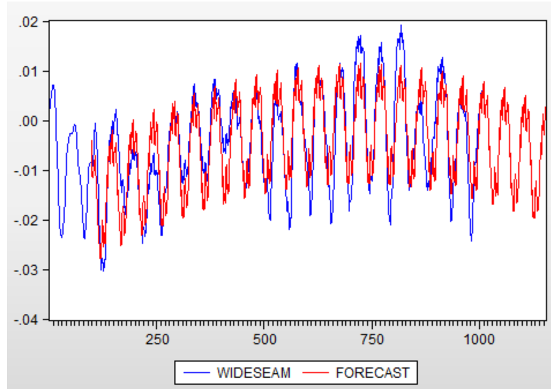
Models	AIC	SC
ARIMA(1, 1, 1) × (0, 1, 1)48	9.36	9.26
ARIMA(1, 1, 1) × (1, 1, 0)48	9.383	9.283
ARIMA(1, 1, 1) × (1, 1, 1)48	10.323	10.255

Figure 3 Narrow seam model fitting statistics table

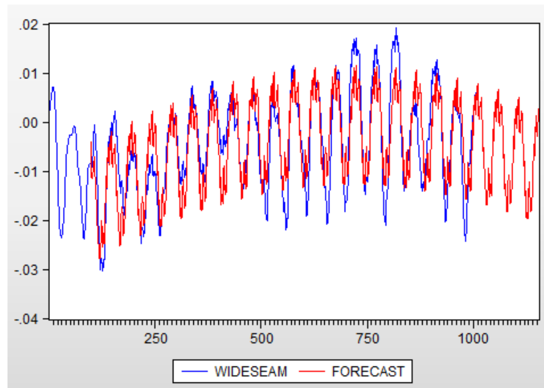
In Table 3, the AIC and SC values of the ARIMA (1, 1, 1) × $(0, 1, 1)_{48}$ model are smaller and can be determined as the final model.

2.3 Model prediction

The main purpose of modeling is to predict the deformation of the wide and narrow seam in future observation periods by means of existing observations. In order to verify the accuracy and prediction accuracy of the model fitting, 3 weeks of 1008 monitoring data were used to establish a model to predict 144 deformation values of the wide and narrow seam in the next three days, as shown in Figure 5 (Fig. 5a, 5b). As shown, the monitoring data is close to the model fitting values. The wide and narrow seam data of the next 3 days (1009~1152) are predicted, as shown in Figure 5 (the red indicates the model prediction value)



Picture 5a Wide seam forecasting



Picture 5b Narrow seam forecasting

Comparing the fitting values of the wide and narrow seam with the measured data, it can be seen that the fitting value of the overall model can be well matched with the measured value. The maximum error of the wide seam is no more than 0.008 mm, and the maximum error of the narrow seam is about 0.06 mm. The accuracy requirements of the track slab prediction indicate that the model is ideal.

3. Conclusion

According to the deformation characteristics of wide and narrow seam of the track slab to establish the time series model fully explore the information contained in the time series and predict the deformation in the future. It verifies that the model has a good fitting effect and high prediction accuracy.

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